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2. DESIGN ANALYSIS TITLE	
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# Waste Package Development

# Design Analysis

Title: Calculational Methodology for Nitric Acid Production by Alpha Particles in Spent Fuel  
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## 1. Purpose

This analysis is prepared by the Mined Geologic Disposal System (MGDS) Waste Package Development Department (WPDD) to provide a methodology for the calculation of nitric acid production by alpha particles generated by spent Light Water Reactor (LWR) fuel in a waste package. The objective is to obtain a nitric acid production rate per Pressurized Water Reactor (PWR) assembly from 100 to 1,000 years. The cumulative production of nitric acid for any time period can be calculated, if desired, from the data provided in this report. Analyses of nitric acid formation for other types of fuel or for other time periods could be performed using this methodology.

It should be noted that this analysis is dependent upon the assumptions of spent nuclear fuel cladding damage (see assumption 4.3.2) and the presence of moist air in the waste package (see assumption 4.3.3), whereas these conditions are in conflict with the goals of waste package design. If the cladding remains intact, or if the waste package is filled with an inert gas, no nitric acid will be formed at all. This analysis does not evaluate the relative probabilities of these conditions. The cladding of spent nuclear fuel is impervious to alpha particles because the penetration (range) of the particles is less than the thickness of the cladding, and intact fuel cladding thus prevents alpha particles from reaching the moist air environment required to form nitric acid. Moist air is required to provide the nitrogen, oxygen and hydrogen needed to form nitric acid, and the inert atmosphere present in a waste package denies these chemicals so that the chemical reaction can not take place.

## 2. Quality Assurance

The Quality Assurance (QA) program applies to this analysis. The work reported in this document is part of the Waste Package (WP) preliminary design analysis that will eventually support the License Application Design phase. This activity, when appropriately confirmed, can impact the proper functioning of the MGDS waste package; the waste package has been identified as an MGDS Q-List item important to safety and waste isolation (pp. 4, 15, Ref. 5.1). The waste package is on the Q-List by direct inclusion by the Department of Energy (DOE), without conducting a QAP-2-3 evaluation. The Waste Package Development Department (WPDD) responsible manager has evaluated this activity in accordance with QAP-2-0, *Conduct of Activities. The Perform Criticality, Thermal, Structural, and Shielding Analyses* (Reference 5.2) evaluation has determined the preparation and review of this design analysis is subject to *Quality Assurance Requirements and Description* (QARD; Ref. 5.3) requirements. As specified in NLP-3-18, the development of this analysis is subject to QA controls.

All design inputs which are identified in this document are for the preliminary stage of the WP design process; all of these design inputs will require subsequent confirmation (or superseding inputs) as the waste package design proceeds. Consequently, the use of any data from this analysis

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for input into documents supporting procurement, fabrication, or construction is required to be controlled and tracked as TBV or TBD in accordance with NLP-3-15 or other appropriate procedures.

## 3. Method

The generation of the alpha source is performed by using the SAS2H computer code sequence, which is a part of the SCALE 4.2 system. SAS2H is a sequence of computer codes which model a PWR or Boiling Water Reactor (BWR) fuel assembly to calculate the isotopic contents of the fuel as the assembly is irradiated and later decayed. SAS2H calculates the curie content of spent fuel, and the actinide portion of the radioisotopic inventory contributes to the alpha source. The alpha particles are transported from the interior of the fuel pellet by means of the stopping power methodology, which tracks the instantaneous energy loss of a charged particle as it slows down in matter. The energy deposition of alpha particles which escape the fuel pellet is calculated and transformed to a nitric acid generation rate via the "g-factor", or moles of nitric acid produced per unit energy deposited in moist air. The alpha particle source varies with time as the fuel cools, and hence the nitric acid production rate also varies with time. The nitric acid production rate, as a function of time, is calculated over the time period beginning with five years after discharge from the reactor through 1,000,000 years after discharge.

Both cladding damage (see assumption 4.3.2) and the presence of moist air in the waste package (see assumption 4.3.3) are required to produce nitric acid. If the cladding is intact or if the waste package is filled with an inert gas, no nitric acid will be formed at all. This analysis does not evaluate the relative probabilities of these conditions; rather, the conditions of failed cladding (assumed to be totally absent, for computational purposes, assumption 4.3.2) and moist air present in the waste package are initial conditions for the methodology. The cladding of spent nuclear fuel is impervious to alpha particles because the penetration (range) of the particles is less than the thickness of the cladding, and intact fuel cladding thus prevents alpha particles from reaching the moist air environment required to form nitric acid. Moist air is required to provide the nitrogen, oxygen and hydrogen needed to form nitric acid, and the inert atmosphere present in a waste package denies these chemicals so that the chemical reaction can not take place.

#### **4. Design Inputs**

All design inputs which are identified in this document are for the preliminary stage of the design process; some or all of these design inputs will require subsequent confirmation (or superseding inputs) as the waste package design proceeds. Consequently, the use of any data from this analysis for input into documents supporting procurement, fabrication, or construction is required to be controlled and tracked as TBV or TBD in accordance with NLP-3-15, *To Be Verified (TBV) and To Be Determined (TBD) Monitoring System*, or other appropriate procedures.

##### **4.1 Design Parameters**

The alpha particle source originates from the decay of actinide isotopes present in spent LWR fuel. The source is calculated for 35,000 MWd/MTU, 48,000 MWd/MTU, and 55,000 MWd/MTU, in order to span the range of expected burnups for B&W 15x15 PWR fuel assemblies (see assumption 4.3.1). The initial enrichments for these burnups are respectively 3.30, 4.20, and 5.05 weight percent U-235 (Ref. 5.10). The time period of interest for nitric acid production for this analysis is 100 years through 1,000 years to span the earliest period during which the conditions of damaged cladding (assumption 4.3.2) and moist air (assumption 4.3.3) might occur. This time period is in agreement with the time period evaluated by others (Ref. 5.8). In addition, calculations were performed at five years and from 1,000 through 1,000,000 years to illustrate the variation of nitric acid production during other time periods.

The alpha particle emission energies used for this analysis are the maximum energy for each isotope. Alpha particle emission energies are normally split into a series of lines by quantum mechanical effects, and the use of the maximum energy results in a somewhat conservative (five percent) overestimate of the alpha particle energy. The alpha particle emission energies and the half-life of each isotope included in this analysis are given in Table 4.1-1.

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**Table 4.1-1**  
**Alpha Particle Emission Energies**

Isotope	Energy (MeV)	Half Life (years)
U-234	4.77	$2.47 \times 10^5$
U-235	4.58	$7.1 \times 10^4$
U-238	4.2	$4.51 \times 10^9$
Np-237	4.78	$2.2 \times 10^6$
Pu-238	5.50	86.4
Pu-239	5.16	24,390
Pu-240	5.17	6580
Pu-241	4.9	13.2
Pu-242	4.9	$3.75 \times 10^5$
Am-241	5.49	458
Am-243	5.3	7900

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The stopping powers for an alpha particle is dependent upon the medium through which the alpha particle is passing. Denser media generally have higher stopping powers, and solids have greater stopping powers than liquids or gases. The elemental composition of the medium has a strong effect upon the stopping power, and there is a secondary effect caused by molecular bonding in compounds. Stopping powers are dependent upon the energy of the incident alpha particle. The stopping power of the uranium dioxide fuel pellet is given as a function of alpha particle energy in Table 4.1-2. Table 4.1-2 contains the UO<sub>2</sub> stopping power for energies from zero to six MeV to allow table interpolation for the specific energy of a given alpha particle.

Table 4.1-2  
Stopping Powers for Uranium Dioxide

Stopping Power Tables for Uranium, Oxygen, and UO <sub>2</sub>							
Uranium E (MeV)	Oxygen (Solid)			UO <sub>2</sub>			Per Molecule dE/dx MeV/cm <sup>2</sup> /g
	dE/dx (eV/10 <sup>-15</sup> )	dE/dx MeV-cm <sup>2</sup> /g	E (MeV)	dE/dx (eV/10 <sup>-15</sup> )	dE/dx MeV-cm <sup>2</sup> /g	E (MeV)	
0.10	76.4	183.37	0.10	20.0	753.00	0.10	110.00
0.15	95.6	241.86	0.15	24.3	914.90	0.15	116.40
0.20	111.0	280.94	0.20	27.9	1050.44	0.20	144.20
0.30	136.0	344.22	0.30	33.2	1249.98	0.30	166.80
0.40	154.0	389.77	0.40	37.0	1393.05	0.40	202.40
0.50	166.0	420.15	0.50	39.5	1487.18	0.50	228.00
0.60	173.0	437.86	0.60	41.0	1543.65	0.60	245.00
0.70	177.0	447.99	0.70	41.9	1577.54	0.70	255.00
0.80	179.0	453.05	0.80	42.1	1585.07	0.80	263.20
1.00	176.0	445.46	1.00	41.5	1562.48	1.00	260.80
1.50	158.0	399.90	1.50	37.2	1400.68	1.50	232.40
2.00	141.0	356.87	2.00	32.6	1227.39	2.00	206.20
3.00	116.0	293.60	3.00	25.9	975.14	3.00	167.80
4.00	101.0	255.63	4.00	21.7	817.01	4.00	144.40
5.00	89.8	227.28	5.00	18.9	711.59	5.00	127.80
6.00	81.5	206.28	6.00	16.8	632.62	6.00	115.10

## 4.2 Criteria

The design of the engineered barrier system (EBS) will depend upon the resistance of the waste package materials to corrosive influences. Criteria that relate to the metallurgy of the EBS are derived from the applicable requirements and planning documents. Upper-level systems requirements are provided in the Monitored Geologic Disposal System Requirements Document (MGDSRD, Ref. 5.4). The requirements flow down to the Engineered Barrier Design Requirements Document (EBDRD, Ref. 5.5) as specific requirements for engineered barrier segment design. The Controlled Design Assumptions Document (Ref. 5.6) provides guidance for requirements listed in the EBDRD which have unqualified or unconfirmed data associated with the requirement. The criteria applicable to the development of corrosion resistance for the design of the waste package are equivalent to the applicable requirements, interface requirements, and criteria cited in the MGDSRD and EBDRD and they are listed in this section.

The MGDSRD does not contain any criteria which specifically applies to the development of alpha particle production of nitric acid. The MGDSRD provides criteria for the evaluation of component designs with regard to corrosion resistance, but does not indicate any criteria for the alpha particle production rate of nitric acid used to evaluate designs with regard to the corrosion criteria.

The EBDRD provides the following requirements which relate to the development of corrosion resistance.

- 4.2.1 The design of waste packages shall include, but not be limited to, consideration of the following factors: ..., corrosion, ... [EBDRD 3.7.1.B].
- 4.2.2 The container shall be designed so that neither its in situ chemical, physical and nuclear properties, nor its interactions with the waste form and the emplacement environment, compromise the function of the waste package or the performance of the natural barriers or engineered barriers. [EBDRD 3.7.1.2.G].

## 4.3 Assumptions

Based upon the rationale that the conclusions derived by this analysis are for preliminary design and will not be used as input supporting construction, fabrication, or procurement, a TBD (to be determined) or TBV (to be verified) will not be carried to the conclusions to this analysis.

The assumptions used in this analysis are:

- 4.3.1 The waste package contains 21 BW 15x15 PWR spent fuel assemblies. BW 15x15 PWR assemblies are representative of the fuel which will be disposed of in waste packages since the uranium mass of these assemblies is larger than other common fuel types (Ref. 5.10) Burnups of 35,000 MWd/MTU, 48,000 MWd/MTU, and 55,000 MWd/MTU, are analyzed in order to represent the range of typical PWR burnups. This data is TBV. This assumption is used in Section 4.1 and in Section 7.4.4.
- 4.3.2 The cladding of the fuel rods is substantially damaged so that extensive portions of the surface area of fuel pellets are exposed. One hundred percent exposure is assumed for computational purposes. This data is TBV. This assumption is used in Section 1, Section 3, and Section 7.1. This assumption is based upon engineering judgement that it will result in conservative results.
- 4.3.3 The interior cavity of the waste package is filled with moist air. This assumption is used in Section 1, Section 3, and Section 7.1. This data is TBV. This assumption is based upon engineering judgement that it will result in conservative results.
- 4.3.4 The production of nitric acid is assumed to be 100 eV per molecule (this is termed the "g-factor"). This data is TBV. This assumption is used in Sections 7.2, 7.3, and 7.4.5. The 100 eV/molecule value is provided in reference 5.9.

- 4.3.5 All of the alpha particle energy is absorbed in moist air (the reaction is 100 percent efficient). This assumption is used in Section 7.1. This data is TBV. This assumption is based upon engineering judgement that it produce conservative results.
- 4.3.6 Nitric acid is produced through alpha particle-induced chemical reactions, but is not destroyed and does not leave the package. This assumption is used in Section 7.1. This data is TBV. This assumption is based on engineering judgement that it will result in conservative results.
- 4.3.7 The fuel pellet is assumed to be intact, although it may be cracked. Cracking of the fuel pellet has no effect upon the results of these analyses. This assumption is used in Section 7.4.5. This data is TBV. This assumption is based upon the damaged cladding (see assumption 4.3.2) retaining sufficient integrity to maintain the pellet geometry.
- 4.3.8 The highest emission energy was used for each isotope. This increases the probability of escape from the fuel pellet and also increases the residual energy deposited in the moist air. This assumption will result in conservative energy calculations. This data is TBV. This assumption is used in Section 7.4.1.
- 4.3.9 The isotopes which were included include U-234, U-235, U-238, Np-237, Pu-238, Pu-239, Pu-240, Pu-241, Pu-242, Am-241, and Am-243. This assumption is based upon the significant contribution of these isotopes to the alpha particle source during the time period of 100-1000 years. This data is TBV. This assumption is used in Section 7.4.4.
- 4.3.10 The g-factor for alpha particle production of nitric acid was chosen to be equal to the g-factor for production of nitric acid by gamma radiation. This assumption is based upon the premise that the energy required to form a molecule is essentially independent of the mechanism of formation. This datum is TBV. This assumption is used in Section 7.2.

### 4.4 Codes and Standards

None used.

## 5. References

- 5.1 Yucca Mountain Site Characterization Project Q-List, YMP/90-55Q, REV 4, U.S. Department of Energy (DOE) Office of Civilian Radioactive Waste Management (OCRWM).
- 5.2 QAP-2-0 Activity Evaluation: ID#WP-20, *Perform Criticality, Thermal, Structural, and Shielding Analyses*, Civilian Radioactive Waste Management System (CRWMS) Management and Operating Contractor (M&O), August 3, 1997.
- 5.3 Quality Assurance Requirements and Description, DOE/RW-0333P, REV 7 U.S. DOE OCRWM.
- 5.4 Office of Civilian Radioactive Waste Management Mined Geological Disposal System Requirements Document, DOE/RW-0404P, DI: B00000000-00811-1708-00002 REV 01, DCN01, May 1995
- 5.5 Engineered Barrier Design Requirements Document, YMP/CM-0024, REV 0, ICN 1, Yucca Mountain Site Characterization Project.
- 5.6 Controlled Design Assumptions Document, DI Number: B0000000-01717-4600-00032 REV 04, ICN 02, CRWMS M&O.
- 5.7 Helium - Stopping Powers and Ranges in All Elemental Matter, J.F. Ziegler, Volume 4 of the Stopping and Ranges of Ions in Matter, Pergamon Press, New York, 1977, ISBN 0-08-021606-4.
- 5.8 D.T. Reed and R.A. Van Konynenburg, "Effect of Ionizing Radiation on the Waste Package Environment", in High Level Radioactive Waste Management: *Proceedings of the Second International Conference*, pp. 1396-1403 (American Nuclear Society, La Grange Park, IL, and American Society of Civil Engineers, New York, 1991).
- 5.9 Analysis of Degradation Due to Water and Gases in MPC, DI Number: B0000000-01717-0200-00005 REV 01, CRWMS M&O.
- 5.10 Characteristics of Potential Repository Wastes, DOE/RW-0184-R1 Volume 1, July 1992.
- 5.11 Software Qualification Report for the SCALE Modular Code System (CSCI: 30004 V1.0), DI Number: 30004-2002 REV 00, CRWMS M&O.

- 5.12 Radiological Health Handbook, Revised Edition, 1970, U.S. Dept. of Health, Education, and Welfare.**

## 6. Use of Computer Software

### 6.1 Scientific and Engineering Software

The calculation of the alpha particle source in spent fuel was performed with the SAS2H code sequence (Ref. 5.11), which is a part of the SCALE 4.2 code system version (V) 1.0 (CSCI: 30004 V1.0), to obtain actinide radioisotope inventories. SAS2H is designed for LWR fuel depletion calculations to determine spent fuel isotopic content (including radioisotopes which produce alpha particles), decay heat rates, and radioactive source terms. Thus, SAS2H is appropriate for the generation of isotopic data for the calculations of this analysis. The calculations using the SAS2H software were executed on a Hewlett-Packard 9000 Series 735 workstation. The software qualification of the SAS2H software, including problems related to generation of isotope contents, is summarized in the Software Qualification Report for the SCALE Modular Code system (Ref. 5.11). The SAS2H evaluations performed for this design are fully within the range of the validation for the SAS2H software used, since a PWR fuel assembly is used in this analysis (see assumption 4.3.1). The associated 27BURNUPLIB cross section library was used for these calculations. Access to and use of the SAS2H software for this analysis was granted by Software Configuration Management and performed in accordance with the QAP-SI series procedures. Inputs for the SAS2H software are included as attachments as described in the following design analysis.

### 6.2 Software Routines for Computational Support

Once the alpha particle source has been obtained with the SAS2H software described in Section 6.1 above, the particles are transported through the fuel pellet uranium oxide matrix by means of a Visual Basic subroutine which is an integral part of the Microsoft EXCEL Version 5.0 for Windows spreadsheet, as shown in Attachment I. The fraction of alpha particles per unit time which escape the fuel uranium oxide matrix, and are thus free to interact with moist air to produce nitric acid, is then calculated in the EXCEL spreadsheet.

## 7. Design Analysis

### 7.1 Introduction

The radiation present in the waste package could cause the production of nitric acid if moist air is present, which could enhance the corrosion of materials. There are two types of radiation which might contribute to nitric acid production: alpha particles and gamma radiation (only alpha particles are examined in this document). Neutron radiation is also present; however, the relatively low radiation level and low interaction rate between the neutrons and waste package materials reduce the neutron contribution to inconsequential levels. Beta radiation is essentially confined within the fuel pellet. The gamma radiation suffuses the interior of the waste package, so that moist air within the waste package could produce nitric acid molecules from the nitrogen and water in the air. The alpha particles can not produce nitric acid inside the waste package if the fuel rod cladding is intact (see assumption 4.3.2), because none of the alpha particles can penetrate the zircaloy cladding. If the cladding is breached, moist air (see assumption 4.3.3) could contact the surfaces of the fuel pellets and produce nitric acid. Moist air is required to provide the oxygen and hydrogen which bind with the nitrogen of the air to form nitric acid, whereas an intact waste package excludes these chemical constituents from the waste package. The relative strength of nitric acid production by the alphas is much greater than the gammas, if the fuel cladding is removed so that the alpha particles are free to interact with the moist air. This analysis evaluates the nitric acid formation by alpha particles, based upon the initial conditions of damaged fuel cladding and a breached waste package which has allowed moist air (also present as an initial condition; see assumption 4.3.3) to enter the waste package. The energy of alpha particles may be absorbed within moist air or within fuel or structural materials within the waste package, but a 100 percent efficiency of capture in moist air is used for this analysis (see assumption 4.3.5).

The evaluation of the nitric acid production within the waste package may be evaluated in several steps:

- Calculate the alpha particle energy deposition rate within the fuel zone
- Calculate the nitric acid production rate as a function of time

It is worth noting that this approach has an implicit conservatism in that nitric acid is not only produced, it is also destroyed and may be diluted by flow of moist air into and out from the waste package (see assumption 4.3.6). The magnitude of these effects is not evaluated here, and the integration of nitric acid produced over time will assume that all nitric acid molecules produced remain intact within the waste package.

## 7.2 Alpha Particle Energy Deposition Rate

The alpha particle dose rate must be computed in terms of rad/year, and the production of nitric acid is assumed to be 100 eV (see assumption 4.3.4) per molecule (this is termed the "g-factor"). It is further assumed that both alphas and gammas have the same g-factor (see assumption 4.3.10).

The alpha particle generation rate within a fuel pellet is obtainable from the isotopic assay calculated by the SAS2H computer code sequence. The decay of actinides such as uranium, neptunium, plutonium, and americium may be via beta decay or alpha decay. The alpha decay rate of a mixture of these actinides may be calculated, so that the number of alpha particles and their energies can be derived at various cool times (time after discharge from reactor). The energy of the alpha particle affects its probability of escape from the fuel pellet and hence the alpha particle energy deposition rate. Particles which are emitted from a decaying nucleus will not escape the fuel pellet if their direction of emission takes them deeper within the fuel pellet; only particles emitted in an outward direction from a point near enough to the surface can escape the fuel pellet. The range of the average alpha particle in fuel is about one thousandth of a centimeter (the range of an alpha particle with the mean energy produced by spent nuclear fuel is calculated as part of the methodology of this analysis).

Once the probability of escape of an alpha is known (as a function of emission angle and energy), the known production rate of alphas by the fuel (as a function of time) is sufficient to calculate the eV/year emitted from the surface of the fuel pellet. Assuming that all of this alpha particle energy is absorbed in moist air (assumption 4.3.5), the production of nitric acid in molecules/year (converted to moles per year) is calculated.

The probability of escape for the alpha particles is computed by numerical integration of the emitted particles from a series of layers, or "onion skins", of fuel pellet material. The fraction of alphas emitted at any given angle is constant, since the emission of alpha particles is isotropic. As each particle is emitted, it slows down in the fuel material due to Coulomb interactions with the electron clouds of the uranium and oxygen in the fuel. This energy loss may be expressed as the energy lost per unit length, and is a function of energy. At very high energies (5 MeV), the particle is traveling fast enough that the interaction of the alpha with surrounding electron clouds and nuclei is decreased (due to the smaller deBroglie wavelength of the constituent nucleons), so the value of dE/dx is less. As the particle slows into the keV range, the value of dE/dx increases, and the alpha particle slows down faster. The energy loss per unit length is termed the "stopping power", and values are tabulated in reference 5.7.

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The fraction of alpha energy which is released from the fuel pellet may be evaluated as follows:

Calculate the number of alphas emitted from a layer of fuel per second

Calculate the distance from the middle of the layer to the fuel pellet surface as a function of polar angle

Calculate the energy lost by particles traveling at each angle as  $\Delta E = E_0 - \Sigma (dE/dx) * \Delta x$  for a series of small distance steps until the surface of the pellet is reached. Of course, if the distance from the midlayer to the surface, at a given polar angle, exceeds the range of the alpha particles, then no calculation is necessary since these alphas will not contribute to nitric acid production.

The fraction of alphas which reach the surface at each polar angle may thus be determined for each layer, and the residual energy of each group of alphas is also determined. The total energy deposited in the moist air surrounding the fuel pellet is just the sum of residual energies for each polar angle and each fuel layer.

### **7.3 Nitric Acid Production**

Once the rate of total energy deposition in the moist air has been determined, the production rate of nitric acid molecules is just the energy per unit time deposited in air divided by 100 eV/molecule (see assumption 4.3.4), which provides the number of molecules produced per unit time. The total moles of nitric acid is the sum of the production rate at a given time multiplied by the width of the time interval.

### **7.4 Methodology**

#### **7.4.1 Alpha Particle Energies**

Alpha particles are emitted from an unstable nucleus with nearly a single energy that is characteristic of the isotope. The emission line is split by the quantum spin states of the nucleons comprising the alpha, so that a few dozen different energies of emission may result. A given energy of emission may be tens or hundreds of keV higher or lower than the average. The highest emission energy (with a significant branching ratio) was conservatively used for each isotope in these calculations since a higher energy increases the probability of escape from the fuel pellet and also increases the residual energy deposited in the moist air (assumption 4.3.8). The energies of the alpha particles from actinides were taken from the Radiological Health Handbook (Ref. 5.12).

The simplified alpha energies used for this study are presented in Table 7.4-1. The actinide isotopes included in Table 7.4-1 are present in significant quantities in spent fuel (assumption 4.3.10), as calculated by the SAS2H code sequence. Some of the actinides (Pu-238, Pu-241, and Am-241) have relatively short half-lives and do not contribute much beyond the first hundred years of disposal, but have been included because they are commonly known. The energy listed in column two of the Table 7.4-1 is the value which was used for alpha stopping calculations for the fuel pellet. The energy and abundances (branching ratios) for the main emission lines for each isotope are also given in the table.

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Table 7.4-1  
Alpha Particle Emission Energies

Isotope	Energy (MeV)	Half Life (years)	Comment
U-234	4.77	$2.47 \times 10^5$	Lines at 4.77 (72%) and 4.72 (28%)
U-235	4.58	$7.1 \times 10^5$	Lines at 4.58 (8%), 4.40 (57%) and 4.37 (18%)
U-238	4.2	$4.51 \times 10^5$	Two main lines at 4.15 MeV (25%) and 4.2 Mev (75%)
Np-237	4.78	$2.2 \times 10^6$	Lines at 4.78 (75%) and 4.65 (12%)
Pu-238	5.50	86.4	Lines at 5.50 (72%) and 5.46 (28%)
Pu-239	5.16	24,390	Lines at 5.16 (88%) and 5.11 (11%)
Pu-240	5.17	6580	Lines at 5.17 (76%) and 5.12 (24%)
Pu-241	4.9	13.2	Beta emitter, alpha is 0.0023 percent probable
Pu-242	4.9	$3.75 \times 10^5$	Lines at 4.90 (76%) and 4.86 (24%)
Am-241	5.49	458	Lines at 5.49 (85%) and 5.44 (13%)
Am-243	5.3	7900	Lines at 5.28 (87%) and 5.23 (11.5%)

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### 7.4.2 Alpha Particle Stopping Power

The stopping powers for each element (not isotope) are given in the reference 5.7. The stopping powers for uranium and oxygen are provided in these tables for alpha particles. The stopping power for uranium dioxide must be calculated by summing the contributions from U and O<sub>2</sub>, expressed in terms of stopping per atom. The stopping power reference provides stopping powers expressed in terms of stopping power per 10<sup>15</sup> atoms, so the number of atoms of uranium and of oxygen are computed from the 10.41 g/cm<sup>3</sup> density of UO<sub>2</sub> (equivalent to 95% of the theoretical density of UO<sub>2</sub>). The stopping powers for oxygen are provided for oxygen in the gaseous state, and oxygen in the solid state (as part of a compound), so the solid oxygen values are used since they are more appropriate for a chemical compound form. The stopping power is typically expressed in terms of MeV·cm<sup>2</sup>/g, and the UO<sub>2</sub> values have been converted to these units. The individual element and compound stopping powers are provided in Table 7.4-2. Inspection of Table 7.4-2 shows that the rate of loss of energy increases as the alpha particle slows down from 6 MeV, reaching a maximum at 800 keV. This change is due to the increase in interaction probability as the deBroglie wavelength of the alpha nucleons increases with decreasing energy. The decrease in stopping power below several hundred keV is due to the decrease in the effective charge on the alpha as free electrons temporarily interact with the moving alpha.

**Table 7.4-2**  
**Stopping Powers for Uranium Dioxide**

Stopping Power Tables for Uranium, Oxygen, and UO <sub>2</sub>									
Uranium			Oxygen (Solid)			UO <sub>2</sub>			Per Molecule
E (MeV)	dE/dx (eV/10 <sup>-15</sup> )	dE/dx MeV-cm <sup>2</sup> /g	E (MeV)	dE/dx (eV/10 <sup>-15</sup> )	dE/dx MeV-cm <sup>2</sup> /g	E (MeV)	dE/dx (eV/10 <sup>-15</sup> )	dE/dx MeV-cm <sup>2</sup> /g	
0.10	76.4	193.37	0.10	20.0	763.00	0.10	116.40	259.69	
0.15	95.6	241.96	0.15	24.3	914.90	0.15	144.20	321.71	
0.20	111.0	280.94	0.20	27.9	1050.44	0.20	166.80	372.13	
0.30	136.0	344.22	0.30	33.2	1249.98	0.30	202.40	451.55	
0.40	154.0	389.77	0.40	37.0	1393.05	0.40	228.00	508.67	
0.50	166.0	420.15	0.50	39.5	1487.18	0.50	245.00	546.60	
0.60	173.0	437.66	0.60	41.0	1543.65	0.60	255.00	568.91	
0.70	177.0	447.99	0.70	41.9	1577.54	0.70	260.80	581.84	
0.80	179.0	453.05	0.80	42.1	1585.07	0.80	263.20	587.20	
1.00	176.0	445.46	1.00	41.5	1552.48	1.00	259.00	577.83	
1.50	158.0	399.90	1.50	37.2	1400.58	1.50	232.40	518.48	
2.00	141.0	356.87	2.00	32.6	1227.39	2.00	206.20	460.03	
3.00	116.0	293.60	3.00	25.9	976.14	3.00	167.80	374.36	
4.00	101.0	255.63	4.00	21.7	817.01	4.00	144.40	322.16	
6.00	89.8	227.28	6.00	18.9	711.59	6.00	127.60	284.68	
6.00	81.5	206.28	6.00	16.8	632.62	6.00	115.10	255.78	

### **7.4.3 Alpha Particle Range**

The range of an alpha particle is determined primarily by the energy of emission and the medium through which it is traveling. Ranges of alpha particles in solid materials are quite short, on the order of a thousandth of a centimeter in uranium oxide (as calculated in this analysis). For example, for a 5 MeV alpha particle incident on uranium oxide, the stopping power ( $dE/dx$ ) is 284.68 MeV-cm<sup>2</sup>/g and the density of UO<sub>2</sub> is 10.41 g/cm<sup>3</sup>, so the alpha particle loses 2960.7 MeV/cm. Thus, even with an initial energy of 5 MeV, the range of the alpha particle is quite small. Since the stopping power is a function of the energy, the distance traveled by the particle when its residual energy has reached zero is obtained by a numerical integration of the form:

Initially,  $E = 5 \text{ MeV}$

For each distance step  $\Delta x$ ,

Obtain stopping power at energy  $E$

Calculate the energy lost for this distance step,  $\Delta E = (dE/dx) * \Delta x$

Calculate the remaining energy  $E$  as  $E(\text{remaining}) = E - \Delta E$

Continue stepwise integration until the remaining energy is zero.

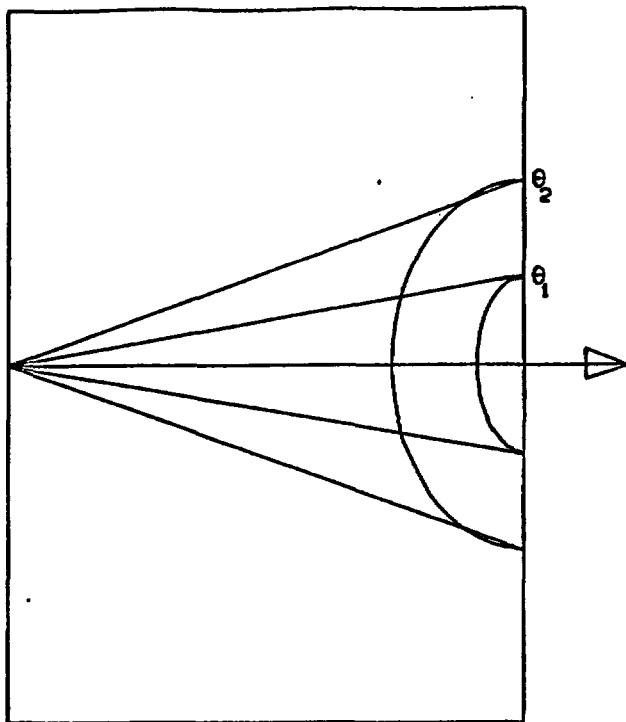


Figure 7.4-1. Effect of Angular Distribution

The distance which a given alpha particle must traverse between the point at which it was first created (in a layer of the fuel pellet) and the surface of the fuel pellet (where it can produce nitric acid molecules) is a function of the angle at which it travels relative to a radius line. Alpha particles are emitted isotropically from the actinide isotopes of spent fuel.

Figure 7.4-1 above depicts alpha particles emitted from a volume element at one side of a slab of uranium dioxide, traveling to the right in the solid angle element defined by angles  $\theta_1$  and  $\theta_2$ . These particles must travel farther than particles which are emitted along a line directly through the slab (indicated by the arrow), and consequently emerge from the slab with a lower residual energy. As the slab becomes thicker, eventually all alpha particles will be stopped completely by the slab. This occurs when the thickness of the slab is equal to the range of the alpha particles in  $\text{UO}_2$ . If the solid angle elements are divided into ten degree increments of  $\theta$ , the probability of emission into a given solid angle element are given by the Table 7.4-3 below. The percentage of alphas emitted into each solid angle element is calculated from the equation:

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$$\text{Fraction} = 2\pi [\cos \theta_2 - \cos \theta_1]$$

The distance which the average particle in the solid angle element must traverse to reach the surface of the slab is given as  $X = (\text{thickness of slab})/\cos\theta$ , where  $\theta$  is the average angle. Thus the distance which any particle, generated within any "onion skin" layer of a fuel pellet, must traverse to escape from the fuel pellet, can be calculated. The ratio of the distance which a particle in a given solid angle element must travel, compared to the thickness of the slab, is given in Table 7.4-3 as the distance factor ( $1/\cos\theta$ ). Once the distance is known, the stopping power table allows the residual energy to be calculated for all alphas within each solid angle element.

Table 7.4-3  
Fractions of Alphas Emitted into Solid Angle Elements

$\theta_1$	$\theta_2$	Fraction	Distance Factor
0	10	0.01519	1.0038
10	20	0.04512	1.0353
20	30	0.07367	1.1034
30	40	0.09998	1.2208
40	50	0.12330	1.4142
50	60	0.14280	1.7430
60	70	0.15800	2.3660
70	80	0.16840	3.8600
80	90	0.17360	11.470

The number of particles traveling at angles between  $\theta_1$  and  $\theta_2$  is the fraction indicated in Table 7.4-3 times the number of particles generated per second. Since the table only includes particles traveling to the right, this result must be divided by two. Because the range of any alpha particle in UO<sub>2</sub> is small compared to the fuel pellet thickness, only particles which are emitted outward have any chance of escape from the pellet. Also, the layer of fuel near the fuel pellet surface which can allow alphas to escape is thin compared to the overall pellet radius, so it is a reasonable approximation to treat the thin layer as a slab, as is done in Table 7.4-3.

**7.4.4 Alpha Source Calculations**

The alpha particle source is obtained from SAS2H calculations for the BW 15x15 PWR fuel assembly with a 48,000 MWd/MTU burnup (see assumption 4.3.1). Calculations are also performed for 35,000 MWd/MTU and 55,000 MWd/MTU in order to span the range of expected burnups. The ORIGEN-S output of the SAS2H run contains the curies of each actinide isotope of interest as a function of cool time. The results of the 48,000 MWd/MTU calculations are tabulated below in Table 7.4-4, at selected cool times of 5, 100, 500, and 1000 years. Detailed calculations at 50 year intervals were included from 100 to 300 years, and at 100 year intervals thereafter, as indicated in the spreadsheets included as attachments to this document. The average energy of alphas emitted from the mixture of actinides is also given.

**Table 7.4-4**  
**Alpha Particle Sources for One PWR Assembly with 48,000 MWd/MTU Burnup**

Isotope	Ci/Asbl @ 100 Years	Ci/Asbl @ 500 Years	Ci/Asbl @ 1000 Years
U-234	0.931	1.38	1.40
U-235	0.00815	0.00822	0.00831
U-238	0.144	0.144	0.144
Np-237	0.336	0.589	0.745
Pu-238	1330.	57.4	1.23
Pu-239	187.	185.	183.
Pu-240	294.	282.	268.
Pu-241	699.	0.284	0.273
Pu-242	1.34	1.34	1.34
Am-241	2630.	1400.	627.
Am-243	18.8	18.1	17.3
Mean E (MeV)	5.45	5.40	5.34

\* Asbl - Assembly

## 7.4.5 Calculation of Alpha Energy Deposited in Moist Air

The short range of alpha particles insures that virtually all of the alphas which escape the fuel pellet will be absorbed in moist air before reaching an adjacent fuel rod or structural material, hence this study treats all of the energy which escapes the pellet as available for the production of nitric acid. The fuel pellet is assumed to be intact (assumption 4.3.7). The production of nitric acid by alpha particles is assumed to be independent of the incident alpha energy; that is, that 100 eV (see assumption 4.3.4) are required for the formation of each nitric acid molecule.

The calculation of the energy which escapes the fuel pellet is performed by the following procedure:

Divide the escape layer of the fuel pellet into twenty zones of equal thickness. The total thickness is just the range of an alpha particle whose energy is equal to the mean energy of all of the actinide emitters. (Note: a check calculation was performed using ten zones to verify that the result has converged.)

For each zone:

- A. Compute the alpha production within the zone, which is equal to the volume fraction of the zone (compared to the pellet) times the total production rate of the pellet.
- B. Compute the track length for each of nine angular groups (at ten degree intervals).

The mean track length for each angular group is equal to the distance factor ( $1/\cos\theta$ ) times the normal distance between the center of the layer and the surface of the pellet.

- C. For each angular group, given the mean track length and the total source for the layer (1/20 of the total source within the zone of escape):

Slow down the alphas by computing:

$E(\text{residual}) = E_0 - \int (dE/dx) dx$ ; integrated in 20 distance steps  $\Delta x$ , where  $\Delta x$  is one twentieth of the mean track length. (Note: the computational results are insensitive to the granularity of the distance steps once there are more than 10.)

So that  $E(\text{residual}) = E_0 - \sum dE/dx(E_{i-1})\Delta x$  summed over i from one to 20.

If  $E \leq 0$ , then cease the iterations - the alpha particles (for this angular group) can not escape.

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If  $E > 0$ , then add the alpha source (for this angular group) times the residual energy to an escaped energy total for this layer. The total energy escaping the pellet is the sum over all 20 fuel layers.

### 7.5 Results

The evaluation of alpha-induced nitric acid production for twenty-one 48,000 MWd/MTU burnup B&W 15x15 PWR fuel assemblies in a waste package shows that 0.3920 moles/year per assembly would be produced at five years cool time, if the waste package were filled with moist air and the spent nuclear fuel cladding were failed, as shown in Table 7.5-1. After the passage of 900 years, this production rate has decreased by a factor of more than three, and continues to decrease thereafter. For the period between 100 and 1000 years, the total moles produced by twenty-one assemblies (with the zircaloy cladding removed) is 2938 moles of nitric acid. (Note: earlier calculations by VanKonynenburg and Reed (Ref. 5.8) obtained 2800 moles for the same time period. This work was based upon Swedish research for copper based waste packages in a repository proposed for Sweden with burnups of 38,000 MWd/MTU for PWR and 33,000 MWd/MTU for BWR fuel assemblies. The much higher design basis burnup of 48,000 MWd/MTU for this work results in a stronger source, although the end results are about the same.)

Table 7.5-1  
Nitric Acid Production for Time Periods up to 1000 Years  
48,000 MWd/MTU Burnup

Alpha Particle Production of Nitric Acid in a Waste Package									
B&W 15x15 ICD 4.2 MTR, 48,000 MWd/MTU									
Time (Years)	Moles/Year,	kg/Year							
6	0.32901	0.02073							
100	0.34412	0.02168							
150	0.29356	0.01849							
200	0.25455	0.01604							
250	0.22520	0.01419							
300	0.20190	0.01272							
400	0.16755	0.01056							
500	0.14357	0.00905							
600	0.12528	0.00789							
700	0.11048	0.00696							
800	0.09891	0.00623							
900	0.08898	0.00561							
1000	0.08059	0.00508							
	Per Asbl	Per Asbl							
Total (100-1000Y)	139.93	8.8153							
			<table border="1"><tr><td>Moles/900Y</td><td>kg/900Y</td></tr><tr><td>Per 21 Asbl</td><td>Per 21 Asbl</td></tr><tr><td>2938.45</td><td>185.12</td></tr></table>	Moles/900Y	kg/900Y	Per 21 Asbl	Per 21 Asbl	2938.45	185.12
Moles/900Y	kg/900Y								
Per 21 Asbl	Per 21 Asbl								
2938.45	185.12								

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The dependence of the nitric acid production rate upon time is illustrated in Figure 7.5-1. The nitric acid production rate decreases rapidly after 100 years and the rate of decrease slows around 500 years. A peak alpha particle production rate occurs prior to the 100 year time period, but is not significant here because waste package failure does not occur until later times.

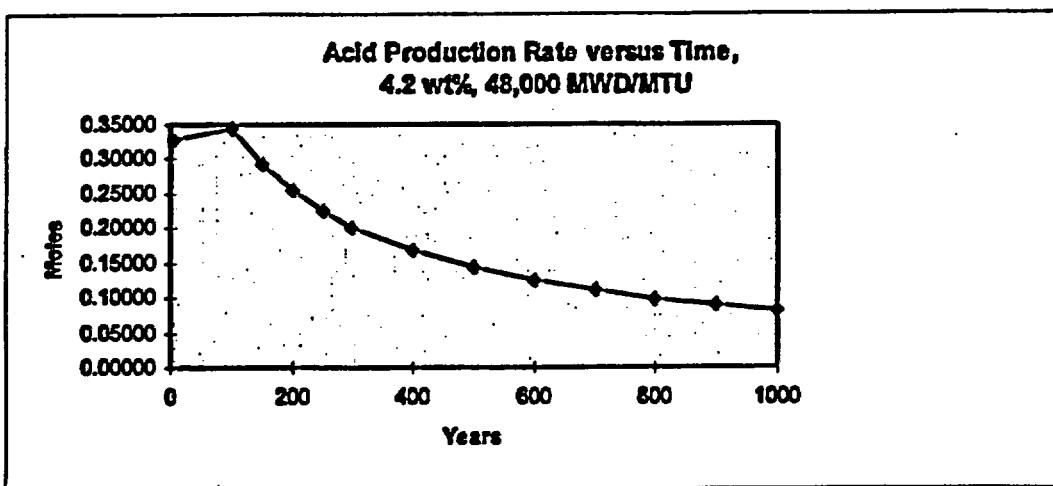


Figure 7.5-1. Nitric Acid Production Rate for 48,000 MWd/MTU Burnup

It should be recalled that the assumptions regarding cladding damage and the presence of moist air are in conflict with the goals of waste package design. If the cladding is intact or if the waste package is filled with an inert gas, no nitric acid will be formed at all. This analysis does not evaluate the relative probabilities of these conditions. The cladding of spent nuclear fuel is impervious to alpha particles because the penetration (range) of the particles is less than the thickness of the cladding, and intact fuel cladding thus prevents alpha particles from reaching the moist air environment required to form nitric acid. Moist air is required to provide the nitrogen, oxygen and hydrogen needed to form nitric acid, whereas the inert atmosphere present in a waste package denies these chemicals so that the chemical reaction can not take place. Over the time period through 1000 years, the waste package and fuel cladding may be expected to remain intact, so that the production of nitric acid would not occur. Over longer periods, failure of waste packages would become more likely, so nitric acid production was evaluated out to one million years, as shown in Table 7.5-2.

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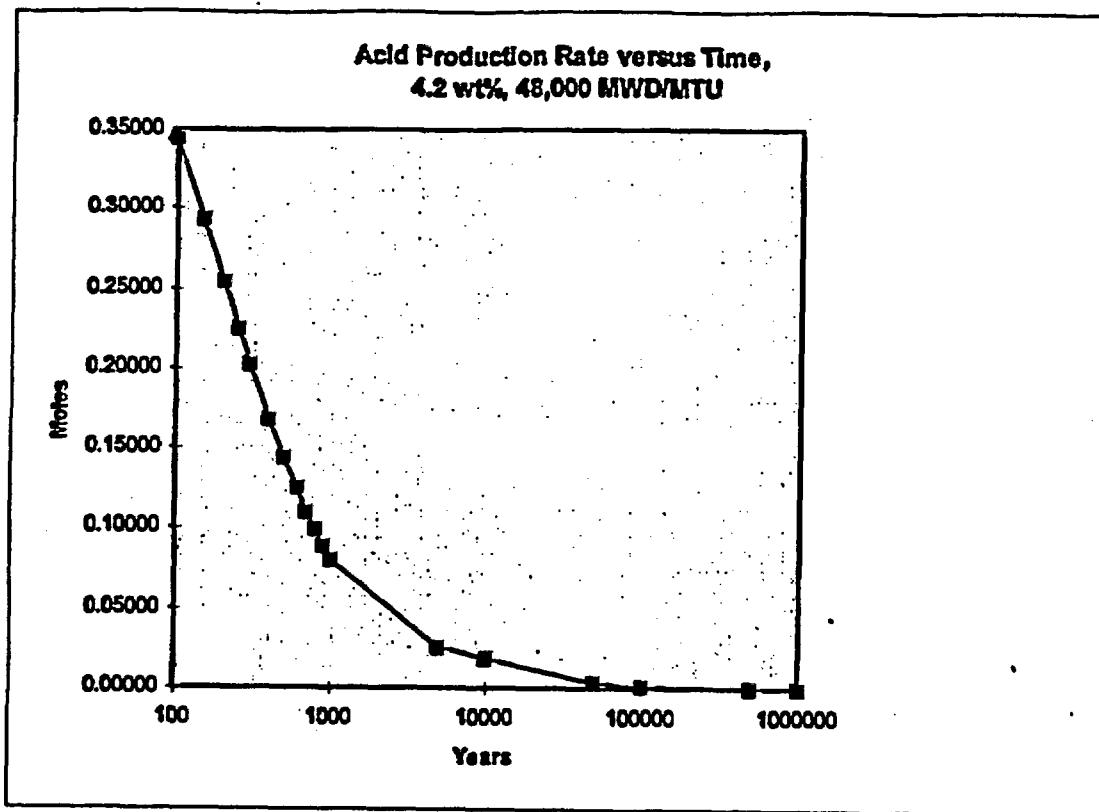
Table 7.5-2  
Nitric Acid Production for Time Periods up to 1,000,000 Years  
48,000 MWd/MTU Burnup

## Alpha Particle Production of Nitric Acid in a Waste Package (Between five years and one million years)

B&W 15x15 @ 4.2 wt%, 48,000 MWd/MTU

Time (Years) Moles/Year kg/Year

5	0.32901	0.02073
100	0.34412	0.02168
150	0.29356	0.01849
200	0.25455	0.01604
250	0.22520	0.01419
300	0.20180	0.01272
400	0.16755	0.01056
500	0.14367	0.00905
600	0.12528	0.00789
700	0.11048	0.00696
800	0.09891	0.00623
900	0.08898	0.00561
1000	0.08059	0.00508
5000	0.02588	0.00163
10000	0.01868	0.00118
50000	0.00367	0.00023
100000	0.00099	0.00006
500000	0.00011	0.00001
1000000	0.00007	0.00000



**Figure 7.5-2. Nitric Acid Production Rate for 48,000 MWd/MTU Burnup to 1,000,000 Years**

Inspection of Figure 7.5-2 shows that the production rate for alpha-induced nitric acid decreases by a factor of four from 100 to 1000 years, and by a further factor of four from 1000 to 10,000 years. For very long time periods, the production rate diminishes substantially, decreasing by a factor of twenty between 10,000 years and 1,000,000 years.

Similar calculations were performed for burnups of 35,000 MWd/MTU and 55,000 MWd/MTU to evaluate the dependence of nitric acid production upon burnup. Results for the 35,000 MWd/MTU burnup are shown in Table 7.5-3 and Figure 7.5-3, and results for the 55,000 MWd/MTU burnup are shown in Table 7.5-4 and Figure 7.5-4.

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Table 7.5-3  
Nitric Acid Production  
35,000 MWd/MTU Burnup

Alpha Particle Production of Nitric Acid for Waste Package		
EXW 16x16x3.3 SW% 35,000 MWd/MTU		
Time (Years)	Moles/Year	kg/Year
5	0.1987	0.0125
100	0.2457	0.0155
150	0.2158	0.0136
200	0.1916	0.0121
250	0.1724	0.0109
300	0.1568	0.0099
400	0.1328	0.0084
500	0.1155	0.0073
600	0.1014	0.0064
700	0.0903	0.0057
800	0.0808	0.0051
900	0.0730	0.0046
1000	0.0663526	0.0042
Per Asbl	Per Asbl	
Total (100-1000Y)	109.59	6.9042

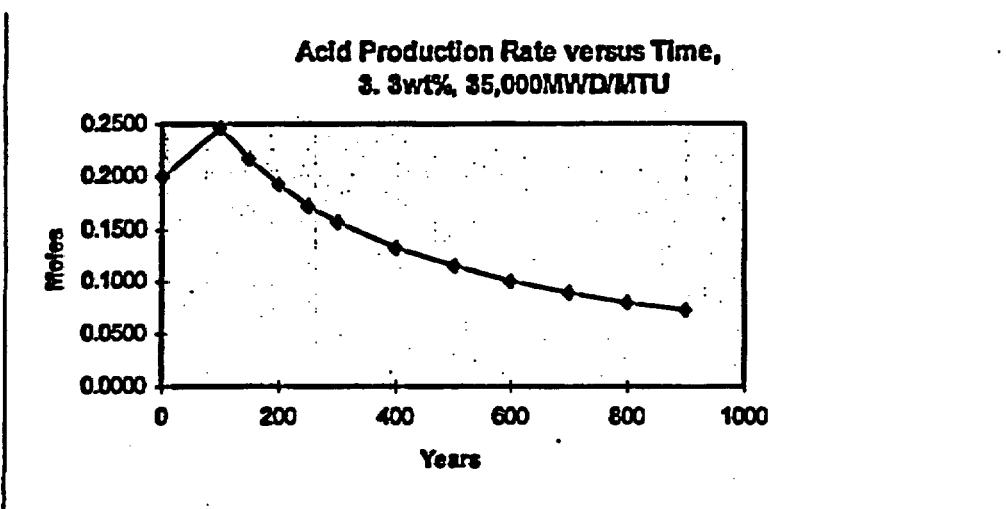


Figure 7.5-3. Nitric Acid Production for 35,000 MWd/MTU Burnup

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Table 7.5-4  
Nitric Acid Production  
55,000 MWd/MTU Burnup

Alpha Particle Production of Nitric Acid in Waste Package		
B&W 15x15 C 6.05 wt% 55,000 MWd/MTU		
Time (Years)	Moles/Year	kg/Year
6	0.4212	0.0265
100	0.4095	0.0258
150	0.3459	0.0218
200	0.2968	0.0187
250	0.2585	0.0163
300	0.2309	0.0145
400	0.1900	0.0120
500	0.1620	0.0102
600	0.1405	0.0089
700	0.1238	0.0078
800	0.1106	0.0070
900	0.0992	0.0063
1000	0.0897	0.0056
Per Asbl	Per Asbl	
Total (100-1000Y)	159.76	10.0648

Moles/800Y kg/800Y  
Per 21 Asbl Per 21 Asbl  
3354.92 211.36

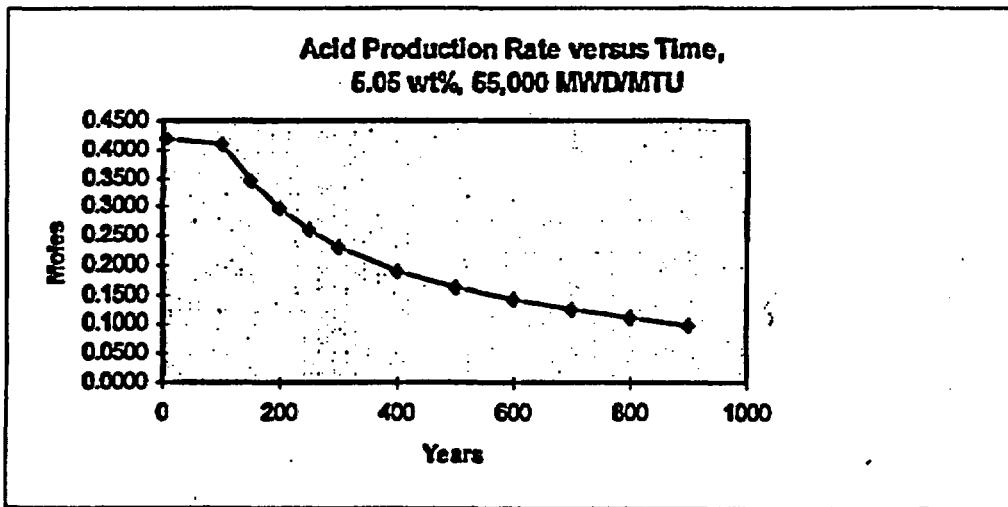


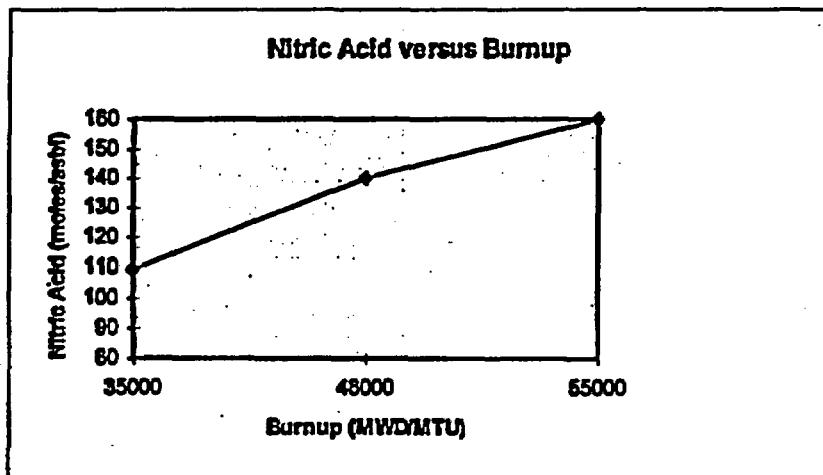
Figure 7.5-4. Nitric Acid Production for 55,000 MWd/MTU Burnup

## 8. Conclusions

As identified in Section 4, this analysis is based on unqualified/unconfirmed input data and use of any data from this analysis for input into documents supporting procurement, construction, or fabrication is required to be controlled and tracked as TBV or TBD in accordance with NLP-3-15, *To Be Verified (TBV) and To Be Determined (TBD) Monitoring System*, or other appropriate procedures.

### 8.1 Nitric Acid Induced by LWR Fuel Alpha Source

The nitric acid production rate is increased by increasing burnup and decreased with additional cool time, as shown in Table 8-1. The values shown assume that moist air fills the waste package and that the zircaloy fuel cladding is substantially degraded. The nitric acid production rate is plotted in Figure 8-1 for the time period from 100 to 1000 years. Inspection of this figure shows that over the range of interest of burnups from 35,000 to 55,000 MWd/MTU, the nitric acid production rises almost linearly. This is due to the dominance of Am-241, Pu-239, and Pu-240. At short cool times (<100 years), Pu-238 is as important as Am-241.



**Figure 8-1. Nitric Acid Production (per Assembly for 100-1000 years) versus Burnup**

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Table 8-1  
Nitric Acid Production versus Burnup

Burnup:	35,000 MWd/MTU	48,000 MWd/MTU	55,000 MWd/MTU
Cool Time, years	(Moles/Asbl/Year)	(Moles/Asbl/Year)	(Moles/Asbl/Year)
5	0.1987	0.3290	0.4212
100	0.2457	0.3441	0.4095
150	0.2158	0.2936	0.3459
200	0.1916	0.2545	0.2968
250	0.1724	0.2252	0.2595
300	0.1568	0.2019	0.2309
400	0.1328	0.1675	0.1900
500	0.1155	0.1437	0.1620
600	0.1014	0.1253	0.1405
700	0.0903	0.1105	0.1238
800	0.0808	0.0989	0.1106
900	0.0730	0.0890	0.0992
1000	0.0664	0.0806	0.0897
Total (100-1000 yrs), moles	109.6	139.9	159.8
Total (21 Assemblies), moles	2301.39	2938.45	3354.92

### **8.2 Future Plans**

A basic assumption of the alpha particle production of nitric acid is that the alpha particles are able to interact with moist air present in the waste package, in the absence of the shielding effect of the fuel rod cladding. The general level of probability of these conditions should be evaluated in the range of 100-1000 years and the cumulative probability of nitric acid production in one or more waste packages could then be determined. Studies related to the effect of nitric acid on the internal structures of the waste package are in progress, and the overall effect on the confinement of radioactive material within the waste package and the repository could then be evaluated.

The effect of gamma radiation on the production of nitric acid has been estimated for waste packages in reference 5.9. The results of the alpha analysis could be factored into the degradation study.

**Attachment I: Visual Basic Code**

The Visual Basic computer code used to calculate the energy of alphas escaping from each layer of the fuel pellet, as a function of angle, follows:

**Mean Energy Escaped Per Source Particle in a Thickness Layer****Function EBAR(EZERO, LMAX, LX)**

- EZERO IS THE INITIAL ENERGY, LMAX IS THE MAXIMUM RANGE
- L IS THE MINIMUM PATH DISTANCE TO THE ESCAPE SURFACE.
- Static ANGS(1 To 18), L(1 To 18), ENG(1 To 18)
- ANGS IS THE LIST OF ISOTROPIC ISOTROPIC EMISSIONS AS A FUNCTION
- OF AZIMUTHAL ANGLE. ANGS(1) CONTAINS THE FRACTION OF PARTICLES
- EMITTED BETWEEN ZERO AND 5 DEGREES, ANGS(2) CONTAINS THE FRACTION
- FOR 5 TO 10 DEGREES, AND SO ON. ZERO DEGREES IS THE NORMAL TO THE ESCAPE SURFACE.

ANGS(1) = 0.003805 · ZERO TO 5 DEGREES

ANGS(2) = 0.011387 · 5 TO 10 DEGREES

ANGS(3) = 0.018882 · 10 TO 15 DEGREES

ANGS(4) = 0.026233 · 15 TO 20 DEGREES

ANGS(5) = 0.033385 · 20 TO 25 DEGREES

ANGS(6) = 0.040282 · 25 TO 30 DEGREES

ANGS(7) = 0.046873 · 30 TO 35 DEGREES

ANGS(8) = 0.053108 · 35 TO 40 DEGREES

ANGS(9) = 0.058938 · 40 TO 45 DEGREES

ANGS(10) = 0.064319 · 45 TO 50 DEGREES

ANGS(11) = 0.069211 · 50 TO 55 DEGREES

ANGS(12) = 0.073576 · 55 TO 60 DEGREES

ANGS(13) = 0.077382 · 60 TO 65 DEGREES

ANGS(14) = 0.080598 · 65 TO 70 DEGREES

ANGS(15) = 0.083201 · 70 TO 75 DEGREES

ANGS(16) = 0.085171 · 75 TO 80 DEGREES

ANGS(17) = 0.086492 · 80 TO 85 DEGREES

ANGS(18) = 0.087156 · 85 TO 90 DEGREES

esum = 0

L(1) = 1.000953 \* LX

L(2) = 1.008629 \* LX  
L(3) = 1.02428 \* LX  
L(4) = 1.048529 \* LX  
L(5) = 1.08392 \* LX  
L(6) = 1.127382 \* LX  
L(7) = 1.185689 \* LX  
L(8) = 1.260472 \* LX  
L(9) = 1.356342 \* LX  
L(10) = 1.480187 \* LX  
L(11) = 1.64268 \* LX  
L(12) = 1.861159 \* LX  
L(13) = 2.165681 \* LX  
L(14) = 2.613126 \* LX  
L(15) = 3.32551 \* LX  
L(16) = 4.620226 \* LX  
L(17) = 7.661298 \* LX  
L(18) = 22.92559 \* LX

For ix = 1 To 18

If (L(ix) >= LMAX) Then Exit For  
ENG(ix) = EFINAL(EZERO, L(ix))  
esum = esum + (ANGS(ix) \* ENG(ix))  
Next ix  
EBAR = esum

End Function

' STOPPINGPOWER Macro  
' STOPPING POWER IN UO2

Function STOPPINGPOWER(EZERO)

Static E(1 To 18), S(1 To 18)

E(1) = 0#

E(2) = 0.1

E(3) = 0.15

E(4) = 0.2

E(5) = 0.3

E(6) = 0.4

E(7) = 0.5

E(8) = 0.6

E(9) = 0.7

E(10) = 0.8

E(11) = 1#

E(12) = 1.5

E(13) = 2#

E(14) = 3#

E(15) = 4#

E(16) = 5#

E(17) = 6#

E(18) = 10

S(1) = 250#

S(2) = 259.69

S(3) = 321.71

S(4) = 372.13

S(5) = 451.55

S(6) = 508.67

S(7) = 546.6

S(8) = 568.91

S(9) = 581.84

S(10) = 587.2

S(11) = 577.83

S(12) = 518.48

S(13) = 460.03

S(14) = 374.36

S(15) = 322.16

S(16) = 284.68

S(17) = 256.79

S(18) = 255

For I = 1 To 18

If (E(I) > EZERO) Then K = I

If (E(I) > EZERO) Then Exit For

Next I

J = K - 1

DELTAE = E(K) - E(J)

DELTAE0 = EZERO - E(J)

EFRAC = DELTAE0 / DELTAE

S1 = S(J)

S2 = S(K)

DELTAS = EFRAC \* (S(K) - S(J))

STOPPINGPOWER = (S1 + DELTAS) \* 10.4

End Function

' STOP1 Macro

' Macro recorded 5/25/96 by wpd

'

' Function STOP1(EZERO)

E1 = EZERO - 0.1

STOP1 = E1

Exit Function

End Function

' RANGE Macro  
' Range of an Alpha Particle based on initial energy

'  
Function ERANGE(EZERO)  
' ActiveCell.FormulaR1C1 = "=DATE(91,1,1)"  
' RANGE("H19").Select

E1 = EZERO  
DELTAX = 0.00001  
For I = 1 To 99  
STOPPING = STOPPINGPOWER(E1)  
E1 = E1 - (STOPPING \* DELTAX)  
If (E1 <= 0#) Then Exit For  
TOTALX = TOTALX + DELTAX  
Next I

ERANGE = TOTALX  
End Function

Function EPRIME(EZERO, DELTAX)

E1 = EZERO  
STOPPING = STOPPINGPOWER(E1)  
E1 = E1 - (STOPPING \* DELTAX)

EPRIME = E1  
End Function

## Attachment II: EXCEL Spreadsheets for 35,000 MWd/MTU

Worksheet for Alpha Particle Transport Calculation Five Years Cool Time						
Material: UO2 B&W15x15, 3.30w/oU-235 35,000 MWd/MTU	Density: Maximum	10.4 (gram/cc)	Radius: (cm)	0.4845		
Source (Ci/Asbl)	Energy (MeV)	Abundance Fraction	Source (s/second)	Power (MeV/s)	Fraction of Total P	
U-234	3.42E-01	4.77	1.00	1.265E+10	6.036E+10	0.0001
U-235	8.20E-03	4.58	0.83	2.518E+08	1.153E+09	0.0000
U-238	1.47E-01	4.20	1.00	5.439E+09	2.284E+10	0.0000
Np-237	1.75E-01	4.78	0.87	5.633E+09	2.693E+10	0.0001
Pu-238	1.47E+03	5.50	1.00	5.439E+13	2.891E+14	0.6204
Pu-239	1.73E+02	5.16	0.99	6.837E+12	3.270E+13	0.0678
Pu-240	2.45E+02	5.17	1.00	8.065E+12	4.687E+13	0.0972
Pu-241	8.54E+04	4.80	2.30E-05	4.715E+10	2.310E+11	0.0005
Pu-242	8.06E-01	4.80	1.00	3.852E+10	1.643E+11	0.0003
Am-241	8.71E+02	5.49	0.87	1.838E+13	1.009E+14	0.2093
Am-243	1.03E+01	5.30	1.00	3.811E+11	2.020E+12	0.0042
		Total:	8.866E+13	4.821E+14	1.0000	
		Mean Source Alpha Energy: (MeV)	5.44			
		Maximum Range for Alphas:	1.374E-03			
Pellet Radius:	0.4845					
Range (cm):	1.374E-03					
Non-escape R:	0.4831					
Escape Fraction:	0.0028319 (Half-Space, Portion of the Source which MIGHT Escape))					
Mean Energy:	5.44					
DeltaX: (cm)	6.870E-05					
Number of Steps:	20 (EBAR Values)					
PATH (cm)	1.340E-03	0.0011139 19.5 Layers	6.526E-04	1.1363748 9.5 Layers		
	1.271E-03	0.0123689 18.5 Layers	5.839E-04	1.3843173 8.5 Layers		
	1.202E-03	0.0433895 17.5 Layers	5.152E-04	1.6550361 7.5 Layers		
	1.134E-03	0.0977588 16.5 Layers	4.465E-04	1.9706867 6.5 Layers		
	1.065E-03	0.1758842 15.5 Layers	3.778E-04	2.3081177 5.5 Layers		
	9.961E-04	0.2770894 14.5 Layers	3.091E-04	2.6874289 4.5 Layers		
	9.274E-04	0.39998975 13.5 Layers	2.404E-04	3.1371480 3.5 Layers		
	8.587E-04	0.5493814 12.5 Layer	1.717E-04	3.6884453 2.5 Layers		
	7.900E-04	0.7209697 11.5 Layers	1.030E-04	4.2068113 1.5 Layers		
	7.213E-04	0.9146604 10.5 Layers	3.435E-05	4.8722908 0.6 Layers		
		1.51	Average MeV for Escaping Alphas			
		8.866E+13	Source Particles/second			
		2.511E+11	Particles/sec POTENTIALLY Escaping			
		3.796E+11	MeV/second Escaping			
		3.796E+15	Molecules/second Formed			
		0.1987	Moles / Year per Asbl			
		0.0125	Kilograms /Year per Asbl			

Worksheet for Alpha Particle Transport Calculation One Hundred Years Cool Time						
Material: UO <sub>2</sub>	Density:	10.4	Radius:	0.4845		
B&W15x15, 3.30w/oU-235	(gram/cc)		(cm)			
35,000 MWD/MTU	Maximum					
Source (Ci/Asbl)	Energy (MeV)	Abundance Fraction	Source (a/second)	Power (MeV/s)	Fraction of Total P	
U-234	6.18E-01	4.77	1.00	2.290E+10	1.092E+11	0.0002
U-235	8.22E-03	4.58	0.83	2.524E+08	1.156E+09	0.0000
U-238	1.47E-01	4.20	1.00	5.439E+09	2.284E+10	0.0000
Np-237	2.33E-01	4.78	0.87	7.500E+09	3.585E+10	0.0001
Pu-238	6.97E+02	5.50	1.00	2.579E+13	1.418E+14	0.2384
Pu-239	1.73E+02	5.16	0.89	6.337E+12	3.270E+13	0.0550
Pu-240	2.45E+02	5.17	1.00	9.065E+12	4.687E+13	0.0788
Pu-241	6.62E+02	4.80	2.30E-05	4.783E+08	2.343E+09	0.0000
Pu-242	9.06E-01	4.80	1.00	3.352E+10	1.643E+11	0.0003
Am-241	2.10E+03	5.49	0.87	6.760E+13	3.711E+14	0.6239
Am-243	1.02E+01	5.30	1.00	3.774E+11	2.000E+12	0.0034
		Total:	1.092E+14	5.949E+14	1.0000	
		Mean Source Alpha Energy: (MeV)	5.45			
		Maximum Range for Alphas:	1.377E-03			
Pellet Radius:	0.4845					
Range (cm):	1.377E-03					
Non-escape R:	0.4831					
Escape Fraction:	0.0028381	(Half-Space, Portion of the Source which MIGHT Escape))				
Mean Energy:	5.45					
DeltaX: (cm)	6.885E-05					
Number of Steps:	20	(EBAR Values)				
PATH (cm)	1.343E-03	0.0010780	19.5 Layers	6.641E-04	1.1376314	9.5 Layers
	1.274E-03	0.0123050	18.5 Layers	6.852E-04	1.3858718	8.5 Layers
	1.205E-03	0.0432821	17.5 Layers	6.164E-04	1.6569696	7.5 Layers
	1.136E-03	0.0976703	16.5 Layers	4.476E-04	1.9730989	6.5 Layers
	1.067E-03	0.1758619	15.5 Layers	3.787E-04	2.3109414	5.5 Layers
	9.983E-04	0.2771659	14.5 Layers	3.098E-04	2.6908822	4.5 Layers
	9.295E-04	0.4002079	13.5 Layers	2.410E-04	3.1411909	3.5 Layers
	8.606E-04	0.5498322	12.5 Layer	1.721E-04	3.5930613	2.5 Layers
	7.918E-04	0.7216273	11.5 Layers	1.033E-04	4.2123820	1.5 Layers
	7.229E-04	0.9155725	10.5 Layers	3.442E-05	4.9789213	0.5 Layers
			1.51	Average MeV for Escaping Alphas		
			1.092E+14	Source Particles/second		
			3.1E+11	Particles/sec POTENTIALLY Escaping		
			4.693E+11	MeV/second Escaping		
			4.693E+15	Molecules/second Formed		
			0.2457	Moles / Year per Asbl		
			0.0155	Kilograms /Year per Asbl		

Worksheet for Alpha Particle Transport Calculation One Hundred and Fifty Years Cool Time						
Material: UO <sub>2</sub>	Density:	10.4	Radius:	0.4845		
B&W15x15, 3.30w/oU-235	(gram/cc)		(cm)			
35,000 MWD/MTU	Maximum					
Source	Energy	Abundance	Source	Power	Fraction	
(Ci/Asbl)	(MeV)	Fraction	(s/second)	(MeV/s)	of Total P	
U-234	7.01E-01	4.77	1.00	2.594E+10	1.237E+11	0.0002
U-235	8.23E-03	4.58	0.83	2.527E+08	1.158E+09	0.0000
U-238	1.47E-01	4.20	1.00	5.439E+09	2.284E+10	0.0000
Np-237	2.66E-01	4.78	0.87	8.563E+09	4.093E+10	0.0001
Pu-238	4.70E+02	5.50	1.00	1.739E+13	9.665E+13	0.1827
Pu-239	1.72E+02	5.16	0.99	6.300E+12	3.251E+13	0.0621
Pu-240	2.44E+02	5.17	1.00	9.028E+12	4.667E+13	0.0891
Pu-241	6.03E+01	4.90	2.30E-05	4.281E+07	2.097E+08	0.0000
Pu-242	9.06E-01	4.90	1.00	3.352E+10	1.643E+11	0.0003
Am-241	1.86E+03	5.49	0.87	6.309E+13	3.464E+14	0.6816
Am-243	1.02E+01	5.30	1.00	3.774E+11	2.000E+12	0.0038
		Total:	9.626E+13	5.236E+14	1.0000	
		Mean Source Alpha Energy: (MeV)	5.44			
		Maximum Range for Alphas:	1.374E-03			
Pellet Radius:	0.4845					
Range (cm):	1.374E-03					
Non-escape R:	0.4831					
Escape Fraction:	0.0028318 (Half-Space, Portion of the Source which MIGHT Escape))					
Mean Energy:	6.44					
DeltaX: (cm)	6.670E-05					
Number of Steps:	20 (EBAR Values)					
PATH (cm)	1.340E-03	0.0011357	19.5 Layers	6.626E-04	1.1369160	9.5 Layers
	1.271E-03	0.0124262	18.5 Layers	5.839E-04	1.3849145	8.5 Layers
	1.202E-03	0.0435418	17.5 Layers	5.152E-04	1.6556488	7.5 Layers
	1.134E-03	0.0978691	16.5 Layers	4.465E-04	1.9713179	6.5 Layers
	1.065E-03	0.1761619	15.5 Layers	3.778E-04	2.3088044	5.5 Layers
	9.961E-04	0.2774347	14.5 Layers	3.091E-04	2.6880642	4.5 Layers
	9.274E-04	0.4004056	13.5 Layers	2.404E-04	3.1378466	3.5 Layers
	8.587E-04	0.5498109	12.5 Layer	1.717E-04	3.5891567	2.5 Layers
	7.900E-04	0.7214546	11.5 Layers	1.030E-04	4.2074865	1.5 Layers
	7.213E-04	0.9151833	10.5 Layers	3.435E-05	4.9730005	0.5 Layers
		1.51	Average MeV for Escaping Alphas			
		9.626E+13	Source Particles/second			
		2.726E+11	Particles/sec POTENTIALLY Escaping			
		4.123E+11	MeV/second Escaping			
		4.123E+15	Molecules/second Formed			
		0.2158	Moles / Year per Asbl			
		0.0136	Kilograms /Year per Asbl			

Worksheet for Alpha Particle Transport Calculation Two Hundred Years Cool Time						
Material: UO <sub>2</sub>	Density:	10.4	Radius:	0.4845		
B&W15x15, 3.30w/oU-235		(gram/cc)		(cm)		
35,000 MWD/MTU	Maximum					
Source	Energy	Abundance	Source	Power	Fraction	
(Ci/Asbl)	(MeV)	Fraction	(a/second)	(MeV/s)	of Total P	
U-234	7.55E-01	4.77	1.00	2.794E+10	1.332E+11	0.0003
U-235	8.24E-03	4.68	0.83	2.631E+08	1.159E+09	0.0000
U-238	1.47E-01	4.20	1.00	6.439E+09	2.284E+10	0.0000
Np-237	2.86E-01	4.78	0.67	9.628E+09	4.654E+10	0.0001
Pu-238	3.17E+02	5.60	1.00	1.173E+13	6.451E+13	0.1386
Pu-239	1.72E+02	5.16	0.99	6.300E+12	3.251E+13	0.0698
Pu-240	2.42E+02	5.17	1.00	8.954E+12	4.629E+13	0.0994
Pu-241	4.68E+00	4.80	2.30E-05	3.898E+06	1.910E+07	0.0000
Pu-242	9.06E-01	4.80	1.00	3.352E+10	1.643E+11	0.0004
Am-241	1.81E+03	5.49	0.87	5.826E+13	3.199E+14	0.6871
Am-243	1.01E+01	5.30	1.00	3.737E+11	1.981E+12	0.0043
		Total:	8.670E+13	4.655E+14	1.0000	
	Mean Source Alpha Energy: (MeV)			5.43		
	Maximum Range for Alphas:			1.372E-03		
Pellet Radius:	0.4845					
Range (cm):	1.372E-03					
Non-escape R:	0.4831					
Escape Fraction:	0.0028278	(Half-Space, Portion of the Source which MIGHT Escape))				
Mean Energy:	5.43					
DeltaX: (cm)	6.860E-05					
Number of Steps:	20	(EBAR Values)				
PATH (cm)	1.338E-03	0.0011005	19.5 Layers	6.617E-04	1.1346047	9.5 Layers
	1.269E-03	0.0123125	18.5 Layers	5.831E-04	1.3822475	8.5 Layers
	1.200E-03	0.0432318	17.5 Layers	5.145E-04	1.6526868	7.5 Layers
	1.132E-03	0.0974545	16.5 Layers	4.459E-04	1.9679873	6.5 Layers
	1.063E-03	0.1754200	15.5 Layers	3.773E-04	2.3050492	5.5 Layers
	9.947E-04	0.2764430	14.5 Layers	3.087E-04	2.6840286	4.5 Layers
	9.261E-04	0.3991526	13.5 Layers	2.401E-04	3.1332449	3.5 Layers
	8.575E-04	0.5483365	12.5 Layer	1.715E-04	3.6841367	2.5 Layers
	7.889E-04	0.7196938	11.5 Layers	1.029E-04	4.2019294	1.5 Layers
	7.203E-04	0.9131483	10.5 Layers	3.430E-05	4.9666426	0.5 Layers
			1.51	Average MeV for Escaping Alphas		
			8.570E+13	Source Particles/second		
			2.423E+11	Particles/sec POTENTIALLY Escaping		
			3.659E+11	MeV/second Escaping		
			3.659E+15	Molecules/second Formed		
			0.1916	Moles / Year per Asbl		
			0.0121	Kilograms /Year per Asbl		

Worksheet for Alpha Particle Transport Calculation Two Hundred and Fifty Years Cool Time						
Material: UO <sub>2</sub>	Density:	10.4	Radius:	0.4845		
B&W15x15, 3.30w/oU-235	(gram/cc)		(cm)			
35,000 MWD/MTU	Maximum					
Source (Ci/Asbl)	Energy (MeV)	Abundance Fraction	Source (a/second)	Power (MeV/s)	Fraction of Total P	
U-234	7.92E-01	4.77	1.00	2.930E+10	1.398E+11	0.0003
U-235	8.24E-03	4.68	0.83	2.631E+08	1.159E+09	0.0000
U-238	1.47E-01	4.20	1.00	5.439E+09	2.284E+10	0.0001
Np-237	3.24E-01	4.78	0.87	1.043E+10	4.085E+10	0.0001
Pu-238	2.14E+02	5.60	1.00	7.918E+12	4.355E+13	0.1038
Pu-239	1.72E+02	5.18	0.99	6.300E+12	3.251E+13	0.0776
Pu-240	2.41E+02	5.17	1.00	8.917E+12	4.610E+13	0.1099
Pu-241	5.00E-01	4.80	2.30E-05	4.255E+05	2.085E+06	0.0000
Pu-242	9.06E-01	4.80	1.00	3.352E+10	1.643E+11	0.0004
Am-241	1.67E+03	5.49	0.87	6.376E+13	2.951E+14	0.7033
Am-243	1.01E+01	6.30	1.00	3.737E+11	1.981E+12	0.0047
		Total:	7.735E+13	4.196E+14	1.0000	
		Mean Source Alpha Energy: (MeV)	5.43			
		Maximum Range for Alphas:	1.370E-03			
Pellet Radius:	0.4845					
Range (cm):	1.370E-03					
Non-escape R:	0.4831					
Escape Fraction:	0.0028237	(Half-Space, Portion of the Source which MIGHT Escape))				
Mean Energy:	5.43					
DeltaX: (cm)	6.850E-05					
Number of Steps:	20	(EBAR Values)				
PATH (cm)	1.336E-03	0.0010689	19.5 Layers	6.607E-04	1.1323764	9.5 Layers
	1.267E-03	0.0122080	18.5 Layers	6.822E-04	1.3796668	8.6 Layers
	1.199E-03	0.0429432	17.5 Layers	5.137E-04	1.6498154	7.6 Layers
	1.130E-03	0.0969722	16.5 Layers	4.452E-04	1.9647604	6.6 Layers
	1.062E-03	0.1747192	15.5 Layers	3.767E-04	2.3013947	5.6 Layers
	9.932E-04	0.2765037	14.5 Layers	3.082E-04	2.6800878	4.6 Layers
	9.247E-04	0.3979628	13.5 Layers	2.397E-04	3.1287454	3.6 Layers
	8.552E-04	0.5469238	12.5 Layer	1.712E-04	3.5792215	2.5 Layers
	7.877E-04	0.7180036	11.5 Layers	1.027E-04	4.1964713	1.5 Layers
	7.192E-04	0.9111925	10.5 Layers	3.425E-05	4.8603886	0.5 Layers
			1.51	Average MeV for Escaping Alphas		
			7.735E+13	Source Particles/second		
			2.184E+11	Particles/sec POTENTIALLY Escaping		
			3.292E+11	MeV/second Escaping		
			3.292E+15	Molecules/second Formed		
			0.1724	Moles / Year per Asbl		
			0.0109	Kilograms /Year per Asbl		

Worksheet for Alpha Particle Transport Calculation Three Hundred Years Cool Time						
Material: UO2	Density:	10.4	Radius:	0.4845		
B&W 15x15, 3.30w/oU-235	(gram/cc)			(cm)		
35,000 MWD/MTU	Maximum					
Source	Energy	Abundance	Source	Power	Fraction	
(Ci/Asbl)	(MeV)	Fraction	(a/second)	(MeV/s)	of Total P	
U-234	8.17E-01	4.77	1.00	3.023E+10	1.442E+11	0.0004
U-235	8.25E-03	4.58	0.83	2.634E+08	1.160E+09	0.0000
U-238	1.47E-01	4.20	1.00	5.439E+09	2.284E+10	0.0001
Np-237	3.50E-01	4.78	0.87	1.127E+10	5.385E+10	0.0001
Pu-238	1.45E+02	5.60	1.00	6.365E+12	2.951E+13	0.0772
Pu-239	1.72E+02	5.16	0.89	6.300E+12	3.251E+13	0.0850
Pu-240	2.40E+02	5.17	1.00	8.680E+12	4.591E+13	0.1200
Pu-241	1.35E-01	4.80	2.30E-05	1.149E+05	5.629E+05	0.0000
Pu-242	9.06E-01	4.80	1.00	3.352E+10	1.843E+11	0.0004
Am-241	1.54E+03	5.49	0.87	4.857E+13	2.722E+14	0.7116
Am-243	1.00E+01	5.30	1.00	3.700E+11	1.961E+12	0.0051
		Total:	7.057E+13	3.824E+14	1.0000	
		Mean Source Alpha Energy: (MeV)	5.42			
		Maximum Range for Alphas:	1.367E-03			
Pellet Radius:	0.4845					
Range (cm):	1.367E-03					
Non-escape R:	0.4831					
Escape Fraction:	0.0028176	(Half-Space, Portion of the Source which MIGHT Escape))				
Mean Energy:	5.42					
DeltaX: (cm)	6.635E-05					
Number of Steps:	20 (EBAR Values)					
PATH (cm)	1.333E-03	0.0011352	18.5 Layers	6.493E-04	1.1318792	9.5 Layers
	1.264E-03	0.0123521	18.5 Layers	5.810E-04	1.3789474	8.5 Layers
	1.196E-03	0.0432597	17.5 Layers	5.126E-04	1.6487431	7.5 Layers
	1.128E-03	0.0973576	16.5 Layers	4.443E-04	1.9632205	6.5 Layers
	1.059E-03	0.1751298	15.5 Layers	3.759E-04	2.2995318	5.5 Layers
	9.811E-04	0.2769128	14.5 Layers	3.076E-04	2.6775227	4.5 Layers
	8.227E-04	0.3983249	13.5 Layers	2.392E-04	3.1256767	3.5 Layers
	8.544E-04	0.6470744	12.5 Layer	1.709E-04	3.5765875	2.5 Layers
	7.860E-04	0.7180270	11.5 Layers	1.025E-04	4.1918395	1.5 Layers
	7.177E-04	0.9110146	10.5 Layers	3.417E-05	4.9547444	0.5 Layers
			1.61	Average MeV for Escaping Alphas		
			7.057E+13	Source Particles/second		
			1.988E+11	Particles/sec POTENTIALLY Escaping		
			2.895E+11	MeV/second Escaping		
			2.895E+15	Molecules/second Formed		
			0.1568	Moles / Year per Asbl		
			0.0099	Kilograms /Year per Asbl		

Worksheet for Alpha Particle Transport Calculation Four Hundred Years Cool Time						
Material: UO <sub>2</sub>	Density:	10.4	Radius:	0.4845		
B&W15x15, 3.30w/oU-235	(gram/cc)		(cm)			
35,000 MWD/MTU	Maximum					
Source (Ci/Asbl)	Energy (MeV)	Abundance Fraction	Source (a/second)	Power (MeV/s)	Fraction of Total P	
U-234	8.45E-01	4.77	1.00	3.127E+10	1.491E+11	0.0005
U-235	8.27E-03	4.68	0.83	2.640E+08	1.163E+09	0.0000
U-238	1.47E-01	4.20	1.00	6.439E+09	2.284E+10	0.0001
Np-237	3.86E-01	4.78	0.87	1.276E+10	6.093E+10	0.0002
Pu-238	6.62E+01	5.60	1.00	2.449E+12	1.347E+13	0.0415
Pu-239	1.71E+02	5.16	0.99	6.264E+12	3.232E+13	0.0985
Pu-240	2.37E+02	5.17	1.00	8.769E+12	4.634E+13	0.1395
Pu-241	9.85E-02	4.80	2.30E-05	8.982E+04	4.107E+05	0.0000
Pu-242	9.06E-01	4.80	1.00	3.352E+10	1.643E+11	0.0005
Am-241	1.31E+03	5.49	0.87	4.217E+13	2.315E+14	0.7124
Am-243	9.85E+00	5.30	1.00	3.682E+11	1.951E+12	0.0060
		Total:	6.010E+13	3.250E+14	1.0000	
		Mean Source Alpha Energy: (MeV)	5.41			
		Maximum Range for Alphas:	1.363E-03			
Pellet Radius:	0.4845					
Range (cm):	1.363E-03					
Non-escape R:	0.4831					
Escape Fraction:	0.0028093	(Half-Space, Portion of the Source which MIGHT Escape))				
Mean Energy:	5.41					
DeltaX: (cm)	6.615E-05					
Number of Steps:	20	(EBAR Values)				
PATH (cm)	1.329E-03	0.0011098	19.5 Layers	6.474E-04	1.1283704	9.6 Layers
	1.281E-03	0.0122430	18.5 Layers	5.793E-04	1.3748401	8.6 Layers
	1.193E-03	0.0429328	17.5 Layers	5.111E-04	1.6440788	7.6 Layers
	1.124E-03	0.0967648	16.5 Layers	4.430E-04	1.9578538	6.5 Layers
	1.056E-03	0.1742185	15.5 Layers	3.748E-04	2.2934270	5.5 Layers
	9.882E-04	0.2745406	14.5 Layers	3.067E-04	2.6707504	4.5 Layers
	9.200E-04	0.3966641	13.5 Layers	2.385E-04	3.1178945	3.5 Layers
	8.619E-04	0.5450087	12.5 Layer	1.704E-04	3.5670112	2.5 Layers
	7.837E-04	0.7155071	11.5 Layers	1.022E-04	4.1820986	1.5 Layers
	7.156E-04	0.9080236	10.5 Layers	3.407E-05	4.9434723	0.5 Layers
		1.50	Average MeV for Escaping Alphas			
		6.010E+13	Source Particles/second			
		1.688E+11	Particles/sec POTENTIALLY Escaping			
		2.537E+11	MeV/second Escaping			
		2.637E+15	Molecules/second Formed			
		0.1328	Moles / Year per Asbl			
		0.0084	Kilograms /Year per Asbl			

Worksheet for Alpha Particle Transport Calculation Five Hundred Years Cool Time						
Material: UO2	Density:	10.4	Radius:	0.4845		
B&W15x15, 3.30w/oU-235	(gram/cc)		(cm)			
35,000 MWD/MTU	Maximum					
Source (Ci/Asbl)	Energy (MeV)	Abundance Fraction	Source (a/second)	Power (MeV/s)	Fraction of Total P	
U-234	8.68E-01	4.77	1.00	3.176E+10	1.614E+11	0.0005
U-235	8.29E-03	4.68	0.83	2.545E+08	1.166E+09	0.0000
U-238	1.47E-01	4.20	1.00	5.439E+09	2.284E+10	0.0001
Np-237	4.35E-01	4.78	0.87	1.400E+10	6.693E+10	0.0002
Pu-238	3.03E+01	6.50	1.00	1.121E+12	6.166E+12	0.0217
Pu-239	1.71E+02	6.16	0.89	6.264E+12	3.232E+13	0.1139
Pu-240	2.35E+02	6.17	1.00	8.695E+12	4.495E+13	0.1584
Pu-241	8.74E-02	4.80	2.30E-05	8.289E+04	4.061E+05	0.0000
Pu-242	8.06E-01	4.80	1.00	3.352E+10	1.643E+11	0.0006
Am-241	1.12E+03	6.49	0.87	3.605E+13	1.878E+14	0.6976
Am-243	9.86E+00	6.30	1.00	3.648E+11	1.834E+12	0.0068
		Total:	6.258E+13	2.837E+14	1.0000	
		Mean Source Alpha Energy: (MeV)	5.40			
		Maximum Range for Alphas:	1.359E-03			
Pellet Radius:	0.4845					
Range (cm):	1.359E-03					
Non-escape R:	0.4831					
Escape Fraction:	0.0028010	(Half-Space, Portion of the Source which MIGHT Escape))				
Mean Energy:	5.40					
DeltaX: (cm)	6.795E-05					
Number of Steps:	20	(EBAR Values)				
PATH (cm)	1.325E-03	0.0010976	19.5 Layers	6.455E-04	1.1251742	9.5 Layers
	1.257E-03	0.0121573	18.5 Layers	5.778E-04	1.3710877	8.5 Layers
	1.189E-03	0.0426918	17.5 Layers	6.096E-04	1.6397789	7.5 Layers
	1.121E-03	0.0962963	16.5 Layers	4.417E-04	1.8528581	6.5 Layers
	1.053E-03	0.1734748	15.5 Layers	3.737E-04	2.2877245	5.5 Layers
	9.853E-04	0.2735699	14.5 Layers	3.058E-04	2.6643472	4.5 Layers
	9.173E-04	0.3952419	13.5 Layers	2.378E-04	3.1105227	3.5 Layers
	8.494E-04	0.6432007	12.5 Layer	1.699E-04	3.5588380	2.5 Layers
	7.814E-04	0.7132718	11.5 Layers	1.019E-04	4.1727480	1.5 Layers
	7.135E-04	0.9053435	10.5 Layers	3.397E-05	4.9326089	0.5 Layers
			1.50	Average MeV for Escaping Alphas		
			6.258E+13	Source Particles/second		
			1.473E+11	Particles/sec POTENTIALLY Escaping		
			2.207E+11	MeV/second Escaping		
			2.207E+15	Molecules/second Formed		
			0.1155	Moles / Year per Asbl		
			0.0073	Kilograms /Year per Asbl		

Worksheet for Alpha Particle Transport Calculation Six Hundred Years Cool Time						
Material: UO <sub>2</sub>	Density:	10.4	Radius:	0.4845		
B&W15x15, 3.30w/oU-235		(gram/cc)		(cm)		
35,000 MWD/MTU	Maximum					
Source (Ci/Asbl)	Energy (MeV)	Abundance Fraction	Source (a/second)	Power (MeV/s)	Fraction of Total P	
U-234	8.64E-01	4.77	1.00	3.197E+10	1.625E+11	0.0006
U-235	8.30E-03	4.68	0.83	2.649E+08	1.167E+09	0.0000
U-238	1.47E-01	4.20	1.00	6.439E+09	2.284E+10	0.0001
Np-237	4.69E-01	4.78	0.87	1.610E+10	7.216E+10	0.0003
Pu-238	1.39E+01	5.60	1.00	5.143E+11	2.829E+12	0.0113
Pu-239	1.70E+02	5.16	0.99	6.227E+12	3.213E+13	0.1286
Pu-240	2.32E+02	5.17	1.00	8.584E+12	4.438E+13	0.1776
Pu-241	9.66E-02	4.80	2.30E-05	8.221E+04	4.028E+05	0.0000
Pu-242	9.05E-01	4.80	1.00	3.349E+10	1.641E+11	0.0007
Am-241	8.52E+02	5.49	0.87	3.064E+13	1.682E+14	0.6732
Am-243	8.77E+00	5.30	1.00	3.615E+11	1.916E+12	0.0077
		Total:	4.642E+13	2.499E+14	1.0000	
		Mean Source Alpha Energy: (MeV)	5.38			
		Maximum Range for Alphas:	1.355E-03			
Pellet Radius:	0.4845					
Range (cm):	1.355E-03					
Non-escape R:	0.4831					
Escape Fraction:	0.0027828	(Half-Space, Portion of the Source which MIGHT Escape))				
Mean Energy:	5.38					
DeltaX: (cm)	6.775E-05					
Number of Steps:	20	(EBAR Values)				
PATH (cm)	1.321E-03	0.0010854	19.5 Layers	6.436E-04	1.1218865	9.5 Layers
	1.253E-03	0.0120947	18.5 Layers	5.759E-04	1.3673430	8.5 Layers
	1.186E-03	0.0424550	17.5 Layers	5.081E-04	1.6354847	7.5 Layers
	1.118E-03	0.0958324	16.5 Layers	4.404E-04	1.9478719	6.5 Layers
	1.050E-03	0.1727376	15.5 Layers	3.726E-04	2.2820283	5.5 Layers
	9.824E-04	0.2725066	14.5 Layers	3.049E-04	2.6579502	4.5 Layers
	9.146E-04	0.3938271	13.5 Layers	2.371E-04	3.1031585	3.5 Layers
	8.469E-04	0.5414002	12.5 Layer	1.694E-04	3.6506699	2.5 Layers
	7.791E-04	0.7110407	11.5 Layers	1.016E-04	4.1633998	1.5 Layers
	7.114E-04	0.9026723	10.5 Layers	3.387E-05	4.8217480	0.5 Layers
			1.49	Average MeV for Escaping Alphas		
			4.642E+13	Source Particles/second		
			1.296E+11	Particles/sec POTENTIALLY Escaping		
			1.838E+11	MeV/second Escaping		
			1.838E+15	Molecules/second Formed		
			0.1014	Moles / Year per Asbl		
			0.0064	Kilograms /Year per Asbl		

Worksheet for Alpha Particle Transport Calculation Seven Hundred Years Cool Time						
Material: UO <sub>2</sub>	Density:	10.4	Radius:	0.4845		
B&W15x15, 3.30w/oU-235		(gram/cc)		(cm)		
35,000 MWD/MTU	Maximum					
	Source (Ci/Asbl)	Energy (MeV)	Abundance Fraction	Source (a/second)	Power (MeV/s)	Fraction of Total P
U-234	8.66E-01	4.77	1.00	3.204E+10	1.628E+11	0.0007
U-235	8.32E-03	4.58	0.83	2.655E+08	1.170E+09	0.0000
U-238	1.47E-01	4.20	1.00	6.439E+09	2.284E+10	0.0001
Np-237	4.97E-01	4.78	0.87	1.600E+10	7.647E+10	0.0003
Pu-238	6.44E+00	5.60	1.00	2.383E+11	1.311E+12	0.0059
Pu-239	1.70E+02	5.16	0.99	6.227E+12	3.213E+13	0.1440
Pu-240	2.30E+02	5.17	1.00	8.510E+12	4.400E+13	0.1972
Pu-241	8.58E-02	4.90	2.30E-05	8.153E+04	3.895E+05	0.0000
Pu-242	8.05E-01	4.90	1.00	3.349E+10	1.641E+11	0.0007
Am-241	8.11E+02	5.49	0.87	2.611E+13	1.433E+14	0.6425
Am-243	9.68E+00	5.30	1.00	3.582E+11	1.898E+12	0.0085
			Total:	4.153E+13	2.231E+14	1.0000
			Mean Source Alpha Energy: (MeV)	5.37		
			Maximum Range for Alphas:	1.351E-03		
Pellet Radius:	0.4845					
Range (cm):	1.351E-03					
Non-escape R:	0.4831					
Escape Fraction:	0.0027846 (Half-Space, Portion of the Source which MIGHT Escape))					
Mean Energy:	5.37					
DeltaX: (cm)	6.755E-05					
Number of Steps:	20 (EBAR Values)					
PATH (cm)	1.317E-03	0.0010622	19.5 Layers	6.417E-04	1.1185331	9.5 Layers
	1.250E-03	0.0118943	18.5 Layers	5.742E-04	1.3633022	8.5 Layers
	1.182E-03	0.0421482	17.5 Layers	5.066E-04	1.6308829	7.5 Layers
	1.115E-03	0.0952660	16.5 Layers	4.391E-04	1.9425706	6.5 Layers
	1.047E-03	0.1718813	15.5 Layers	3.715E-04	2.2759919	5.5 Layers
	9.795E-04	0.2712774	14.5 Layers	3.040E-04	2.6512350	4.5 Layers
	9.119E-04	0.3922112	13.5 Layers	2.364E-04	3.0954415	3.5 Layers
	8.444E-04	0.5393854	12.5 Layer	1.689E-04	3.5421412	2.5 Layers
	7.768E-04	0.7085690	11.5 Layers	1.013E-04	4.1537090	1.5 Layers
	7.093E-04	0.8997411	10.5 Layers	3.377E-05	4.9105263	0.5 Layers
			1.49	Average MeV for Escaping Alphas		
			4.153E+13	Source Particles/second		
			1.156E+11	Particles/sec POTENTIALLY Escaping		
			1.724E+11	MeV/second Escaping		
			1.724E+15	Molecules/second Formed		
			0.0903	Moles / Year per Asbl		
			0.0057	Kilograms /Year per Asbl		

Worksheet for Alpha Particle Transport Calculation Eight Hundred Years Cool Time						
Material: UO <sub>2</sub>	Density:	10.4	Radius:	0.4845		
B&W15x15, 3.30w/oU-235	(gram/cc)		(cm)			
35,000 MWD/MTU	Maximum					
	Source (Ci/Asbl)	Energy (MeV)	Abundance Fraction	Source (a/second)	Power (MeV/s)	Fraction of Total P
U-234	8.67E-01	4.77	1.00	3.208E+10	1.530E+11	0.0008
U-235	8.34E-03	4.58	0.83	2.561E+08	1.173E+09	0.0000
U-238	1.47E-01	4.20	1.00	6.439E+09	2.284E+10	0.0001
Np-237	5.22E-01	4.78	0.87	1.680E+10	8.032E+10	0.0004
Pu-238	2.99E+00	5.50	1.00	1.106E+11	6.085E+11	0.0030
Pu-239	1.69E+02	5.16	0.99	6.190E+12	3.194E+13	0.1594
Pu-240	2.27E+02	5.17	1.00	8.399E+12	4.342E+13	0.2167
Pu-241	9.50E-02	4.90	2.30E-05	8.085E+04	3.861E+05	0.0000
Pu-242	9.05E-01	4.90	1.00	3.349E+10	1.641E+11	0.0008
Am-241	6.81E+02	5.49	0.87	2.224E+13	1.221E+14	0.6094
Am-243	9.59E+00	5.30	1.00	3.548E+11	1.881E+12	0.0084
			Total:	3.739E+13	2.004E+14	1.0000
			Mean Source Alpha Energy: (MeV)	5.36		
			Maximum Range for Alphas:	1.347E-03		
Pellet Radius:	0.4845					
Range (cm):	1.347E-03					
Non-escape R:	0.4832					
Escape Fraction:	0.0027763	(Half-Space, Portion of the Source which MIGHT Escape))				
Mean Energy:	5.36					
DeltaX: (cm)	6.735E-05					
Number of Steps:	20	(EBAR Values)				
PATH (cm)	1.313E-03	0.0010448	19.5 Layers	6.398E-04	1.1152108	9.5 Layers
	1.246E-03	0.0118082	18.5 Layers	5.725E-04	1.3594096	8.5 Layers
	1.178E-03	0.0418782	17.5 Layers	5.051E-04	1.6264325	7.5 Layers
	1.111E-03	0.0947544	16.5 Layers	4.378E-04	1.8374184	6.5 Layers
	1.044E-03	0.1710547	15.5 Layers	3.704E-04	2.2701226	5.5 Layers
	9.766E-04	0.2701349	14.5 Layers	3.031E-04	2.6446718	4.5 Layers
	9.092E-04	0.3906965	13.5 Layers	2.357E-04	3.0878927	3.5 Layers
	8.419E-04	0.6374757	12.5 Layer	1.684E-04	3.5337812	2.5 Layers
	7.745E-04	0.7062184	11.5 Layers	1.010E-04	4.1441768	1.5 Layers
	7.072E-04	0.8969330	10.5 Layers	3.367E-05	4.8994728	0.5 Layers
			1.49 Average MeV for Escaping Alphas			
			3.739E+13 Source Particles/second			
			1.038E+11 Particles/sec POTENTIALLY Escaping			
			1.543E+11 MeV/second Escaping			
			1.543E+15 Molecules/second Formed			
			0.0808 Moles / Year per Asbl			
			0.0051 Kilograms /Year per Asbl			

Worksheet for Alpha Particle Transport Calculation Nine Hundred Years Cool Time					
Material: UO2	Density:	10.4	Radius:	0.4845	
B&W15x15, 3.30w/oU-235	(gram/cc)		(cm)		
35,000 MWD/MTU	Maximum				
Source (Ci/Asbl)	Energy (MeV)	Abundance Fraction	Source (a/second)	Power (MeV/s)	Fraction of Total P
U-234	8.68E-01	4.77	1.00	3.212E+10	1.632E+11
U-235	8.35E-03	4.68	0.63	2.564E+08	1.174E+09
U-238	1.47E-01	4.20	1.00	5.439E+09	2.284E+10
Np-237	5.42E-01	4.78	0.87	1.745E+10	8.340E+10
Pu-238	1.40E+00	5.60	1.00	5.180E+10	2.849E+11
Pu-239	1.69E+02	5.16	0.99	6.190E+12	3.194E+13
Pu-240	2.25E+02	5.17	1.00	8.325E+12	4.304E+13
Pu-241	9.43E-02	4.80	2.30E-05	8.025E+04	3.932E+05
Pu-242	9.05E-01	4.80	1.00	3.349E+10	1.641E+11
Am-241	5.89E+02	6.49	0.87	1.896E+13	1.041E+14
Am-243	9.60E+00	6.30	1.00	3.515E+11	1.863E+12
			Total:	3.397E+13	1.816E+14
					1.0000
			Mean Source Alpha Energy: (MeV)	6.35	
			Maximum Range for Alphas:	1.342E-03	
Pellet Radius:	0.4845				
Range (cm):	1.342E-03				
Non-escape R:	0.4832				
Escape Fraction:	0.0027660	(Half-Space, Portion of the Source which MIGHT Escape))			
Mean Energy:	6.35				
DeltaX: (cm)	6.710E-05				
Number of Steps:	20 (EBAR Values)				
PATH (cm)	1.308E-03	0.0011012	18.5 Layers	6.374E-04	1.1130134
	1.241E-03	0.0120046	18.5 Layers	6.703E-04	1.3566972
	1.174E-03	0.0420505	17.5 Layers	5.032E-04	1.6230856
	1.107E-03	0.0948892	16.5 Layers	4.361E-04	1.9332621
	1.040E-03	0.1710468	15.5 Layers	3.690E-04	2.2652646
	9.729E-04	0.2699521	14.5 Layers	3.019E-04	2.6387658
	9.058E-04	0.3902778	13.5 Layers	2.348E-04	3.0809817
	8.387E-04	0.5366480	12.5 Layer	1.677E-04	3.6259012
	7.716E-04	0.7050323	11.5 Layers	1.006E-04	4.1346972
	7.045E-04	0.8953144	10.5 Layers	3.355E-05	4.8882127
			Average MeV for Escaping Alphas	1.48	
			Source Particles/second	3.397E+13	
			Particles/sec POTENTIALLY Escaping	9.395E+10	
			MeV/second Escaping	1.394E+11	
			Molecules/second Formed	1.394E+15	
			Moles / Year per Asbl	0.0730	
			Kilograms /Year per Asbl	0.0046	

Worksheet for Alpha Particle Transport Calculation One Thousand Years Cool Time						
Material: UO <sub>2</sub>	Density:	10.4	Radius:	0.4845		
B&W15x15, 3.30w/oU-235	(gram/cc)		(cm)			
35,000 MWD/MTU	Maximum					
Source (Cl/Asb)	Energy (MeV)	Abundance Fraction	Source (a/second)	Power (MeV/s)	Fraction of Total P	
U-234	8.68E-01	4.77	1.00	3.212E+10	1.632E+11	0.0009
U-235	8.37E-03	4.58	0.83	2.570E+08	1.177E+09	0.0000
U-238	1.47E-01	4.20	1.00	5.439E+09	2.284E+10	0.0001
Np-237	5.60E-01	4.78	0.87	1.803E+10	8.617E+10	0.0005
Pu-238	6.60E-01	5.60	1.00	2.442E+10	1.343E+11	0.0008
Pu-239	1.69E+02	6.16	0.99	6.190E+12	3.194E+13	0.1927
Pu-240	2.23E+02	6.17	1.00	8.251E+12	4.266E+13	0.2574
Pu-241	9.35E-02	4.90	2.30E-05	7.957E+04	3.699E+05	0.0000
Pu-242	9.05E-01	4.90	1.00	3.349E+10	1.641E+11	0.0010
Am-241	5.02E+02	5.49	0.87	1.616E+13	8.871E+13	0.5353
Am-243	9.41E+00	5.30	1.00	3.482E+11	1.845E+12	0.0111
			Total:	3.106E+13	1.657E+14	1.0000
			Mean Source Alpha Energy: (MeV)	5.34		
			Maximum Range for Alphas:	1.338E-03		
Pellet Radius:	0.4845					
Range (cm):	1.338E-03					
Non-escape R:	0.4832					
Escape Fraction:	0.0027578	(Half-Space, Portion of the Source which MIGHT Escape))				
Mean Energy:	5.34					
DeltaX: (cm)	6.690E-05					
Number of Steps:	20	(EBAR Values)				
PATH (cm)	1.305E-03	0.0010622	19.5 Layers	6.355E-04	1.1091366	9.5 Layers
	1.238E-03	0.0118614	18.5 Layers	6.686E-04	1.3521914	8.5 Layers
	1.171E-03	0.0418376	17.5 Layers	6.017E-04	1.6180010	7.5 Layers
	1.104E-03	0.0941462	16.5 Layers	4.348E-04	1.9274578	6.5 Layers
	1.037E-03	0.1699598	15.5 Layers	3.678E-04	2.2586848	5.5 Layers
	9.700E-04	0.2684572	14.5 Layers	3.010E-04	2.6315402	4.5 Layers
	9.031E-04	0.3883486	13.5 Layers	2.341E-04	3.0727021	3.5 Layers
	8.362E-04	0.5343016	12.5 Layer	1.672E-04	3.5167954	2.5 Layers
	7.693E-04	0.7021917	11.5 Layers	1.003E-04	4.1244511	1.5 Layers
	7.024E-04	0.8919741	10.5 Layers	3.345E-05	4.8764078	0.5 Layers
			1.48	Average MeV for Escaping Alphas		
			3.106E+13	Source Particles/second		
			8.666E+10	Particles/sec POTENTIALLY Escaping		
			1.267E+11	MeV/second Escaping		
			1.267E+15	Molecules/second Formed		
			0.0664	Moles / Year per Asb!		
			0.0042	Kilograms /Year per Asb!		

Alpha Particle Production of Nitro Acid in Waste Package B&W 15.15 CSDA/HYD 35,000 MWD/MTD		
Time (Years)	Moles/Year	kg/Year
5	0.1987	0.0125
100	0.2457	0.0155
150	0.2158	0.0136
200	0.1916	0.0121
250	0.1724	0.0109
300	0.1568	0.0099
400	0.1328	0.0084
500	0.1155	0.0073
600	0.1014	0.0064
700	0.0903	0.0057
800	0.0808	0.0051
900	0.0730	0.0046
1000	0.0663526	0.0042
Per Asbl		Per Asbl
Total (100-1000Y)	109.69	6.9042

Moles/900Y	kg/900Y
Per 21 Asbl	Per 21 Asbl
2301.39	144.99

## Attachment III: EXCEL Spreadsheets for 48,000 MWd/MTU

Worksheet for Alpha Particle Transport Calculation Five Years Cool Time					
Material: UO <sub>2</sub>	Density:	10.4	Radius:	0.4845	
B&W15x15, 4.20w/oU-235	(gram/cc)		(cm)		
48,000 MWD/MTU	Maximum				
Source (Ci/Asbl)	Energy (MeV)	Abundance Fraction	Source (a/second)	Power (MeV/s)	Fraction of Total P
U-234	4.03E-01	4.77	1.00	1.491E+10	7.113E+10
U-235	8.13E-03	4.58	0.83	2.497E+08	1.143E+09
U-238	1.44E-01	4.20	1.00	5.328E+09	2.238E+10
Np-237	2.63E-01	4.78	0.67	8.466E+09	4.047E+10
Pu-238	2.80E+03	5.50	1.00	1.036E+14	6.698E+14
Pu-239	1.88E+02	6.16	0.89	6.886E+12	3.553E+13
Pu-240	2.91E+02	6.17	1.00	1.077E+13	6.567E+13
Pu-241	6.88E+04	4.80	2.30E-05	5.855E+10	2.869E+11
Pu-242	1.34E+00	4.80	1.00	4.958E+10	2.429E+11
Am-241	7.29E+02	5.49	0.87	2.347E+13	1.288E+14
Am-243	1.90E+01	5.30	1.00	7.030E+11	3.726E+12
		Total:	1.456E+14	7.842E+14	1.0000
		Mean Source Alpha Energy: (MeV)	5.46		
		Maximum Range for Alphas:	1.381E-03		
Pellet Radius:	0.4845				
Range (cm):	1.381E-03				
Non-escape R:	0.4831				
Escape Fraction:	0.0028463	(Half-Space, Portion of the Source which MIGHT Escape))			
Mean Energy:	5.46				
DeltaX: (cm)	6.905E-05				
Number of Steps:	20	(EBAR Values)			
PATH (cm)	1.346E-03	0.0010635	19.5 Layers	6.560E-04	1.1401350
	1.277E-03	0.0123076	18.5 Layers	5.869E-04	1.3888558
	1.208E-03	0.0433447	17.5 Layers	5.179E-04	1.6604797
	1.139E-03	0.0978761	16.5 Layers	4.488E-04	1.9772764
	1.070E-03	0.1762581	15.5 Layers	3.798E-04	2.3157642
	1.001E-03	0.2777859	14.5 Layers	3.107E-04	2.6964533
	9.322E-04	0.4011120	13.5 Layers	2.417E-04	3.1476450
	8.631E-04	0.6510887	12.5 Layer	1.726E-04	3.6002982
	7.941E-04	0.7232444	11.5 Layers	1.036E-04	4.2208351
	7.250E-04	0.9175837	10.5 Layers	3.452E-05	4.9888388
			1.52	Average MeV for Escaping Alphas	
			1.456E+14	Source Particles/sec	
			4.143E+11	Particles/sec POTENTIALLY Escaping	
			6.285E+11	MeV/second Escaping	
			6.285E+15	Molecules/second Formed	
			0.3280	Moles / Year per Asbl	
			0.0207	Kilograms /Year per Asbl	

Worksheet for Alpha Particle Transport Calculation One Hundred Years Cool Time						
Material: UO <sub>2</sub>	Density:	10.4	Radius:	0.4845		
B&W15x15, 4.20w/oU-235	(gram/cc)		(cm)			
48,000 MWD/MTU	Maximum					
Source (Ci/Asbl)	Energy (MeV)	Abundance Fraction	Source (a/second)	Power (MeV/s)	Fraction of Total P	
U-234	9.31E-01	4.77	1.00	3.445E+10	1.643E+11	0.0002
U-235	8.15E-03	4.58	0.83	2.603E+08	1.146E+09	0.0000
U-238	1.44E-01	4.20	1.00	5.328E+09	2.238E+10	0.0000
Np-237	3.36E-01	4.78	0.87	1.082E+10	5.170E+10	0.0001
Pu-238	1.33E+03	5.50	1.00	4.921E+13	2.707E+14	0.3256
Pu-239	1.87E+02	5.16	0.99	6.850E+12	3.635E+13	0.0425
Pu-240	2.94E+02	5.17	1.00	1.088E+13	5.624E+13	0.0677
Pu-241	6.89E+02	4.90	2.30E-05	5.948E+08	2.915E+09	0.0000
Pu-242	1.34E+00	4.90	1.00	4.958E+10	2.429E+11	0.0003
Am-241	2.63E+03	5.49	0.87	8.466E+13	4.648E+14	0.6592
Am-243	1.88E+01	5.30	1.00	6.956E+11	3.687E+12	0.0044
		Total:	1.524E+14	8.312E+14	1.0000	
	Mean Source Alpha Energy: (MeV)	5.45				
	Maximum Range for Alphas:	1.380E-03				
Pellet Radius:	0.4845					
Range (cm):	1.380E-03					
Non-escape R:	0.4831					
Escape Fraction:	0.0028442	(Half-Space, Portion of the Source which MIGHT Escape))				
Mean Energy:	6.45					
DeltaX: (cm)	6.800E-05					
Number of Steps:	20	(EBAR Values)				
PATH (cm)	1.345E-03	0.0010869	19.5 Layers	6.555E-04	1.1400016	9.5 Layers
	1.276E-03	0.0123591	18.5 Layers	5.885E-04	1.3886527	8.5 Layers
	1.207E-03	0.0434586	17.5 Layers	5.176E-04	1.6601599	7.5 Layers
	1.138E-03	0.0980154	16.5 Layers	4.485E-04	1.9768056	6.5 Layers
	1.069E-03	0.1764118	15.5 Layers	3.795E-04	2.3151757	5.5 Layers
	1.000E-03	0.2779524	14.5 Layers	3.105E-04	2.6956384	4.5 Layers
	9.315E-04	0.4012571	13.5 Layers	2.415E-04	3.1466671	3.5 Layers
	8.625E-04	0.5511647	12.5 Layer	1.725E-04	3.6991359	2.5 Layers
	7.935E-04	0.7232812	11.5 Layers	1.035E-04	4.2193361	1.5 Layers
	7.245E-04	0.9175557	10.5 Layers	3.450E-05	4.8870054	0.5 Layers
			1.52	Average MeV for Escaping Alphas		
			1.524E+14	Source Particles/second		
			4.334E+11	Particles/sec POTENTIALLY Escaping		
			6.573E+11	MeV/second Escaping		
			6.573E+15	Molecules/second Formed		
			0.3441	Moles / Year per Asbl		
			0.0217	Kilograms / Year per Asbl		

Worksheet for Alpha Particle Transport Calculation One Hundred and Fifty Years Cool Time						
Material: UO <sub>2</sub>	Density:	10.4	Radius:	.4845		
B&W15x15, 4.20w/oU-235	(gram/cc)		(cm)			
48,000 MWD/MTU	Maximum					
Source	Energy	Abundance	Source	Power	Fraction	
(Ci/Asbl)	(MeV)	Fraction	(s/second)	(MeV/s)	of Total P	
U-234	1.09E+00	4.77	1.00	4.033E+10	1.924E+11	0.0003
U-235	8.16E-03	4.58	0.83	2.506E+08	1.148E+09	0.0000
U-238	1.44E-01	4.20	1.00	5.328E+09	2.238E+10	0.0000
Np-237	3.77E-01	4.78	0.87	1.214E+10	6.801E+10	0.0001
Pu-238	8.84E+02	5.50	1.00	3.308E+13	1.819E+14	0.2561
Pu-239	1.87E+02	5.16	0.89	6.850E+12	3.635E+13	0.0497
Pu-240	2.03E+02	5.17	1.00	1.084E+13	5.605E+13	0.0789
Pu-241	6.27E+01	4.80	2.30E-05	5.336E+07	2.615E+08	0.0000
Pu-242	1.34E+00	4.80	1.00	4.958E+10	2.429E+11	0.0003
Am-241	2.45E+03	5.49	0.87	7.887E+13	4.330E+14	0.6094
Am-243	1.87E+01	5.30	1.00	6.919E+11	3.667E+12	0.0052
		Total:	1.304E+14	7.105E+14	1.0000	
	Mean Source Alpha Energy: (MeV)					5.45
	Maximum Range for Alphas:					1.377E-03
Pellet Radius:	0.4845					
Range (cm):	1.377E-03					
Non-escape R:	0.4831					
Escape Fraction:	0.0028381	(Half-Space, Portion of the Source which MIGHT Escape))				
Mean Energy:	5.45					
DeltaX: (cm)	6.885E-05					
Number of Steps:	20	(EBAR Values)				
PATH (cm)	1.343E-03	0.0011261	19.5 Layers	6.641E-04	1.1388295	9.5 Layers
	1.274E-03	0.0124321	18.5 Layers	5.852E-04	1.3871828	8.5 Layers
	1.205E-03	0.0435972	17.5 Layers	5.164E-04	1.6583268	7.5 Layers
	1.136E-03	0.09813865	16.5 Layers	4.476E-04	1.9744943	6.5 Layers
	1.067E-03	0.1764767	15.5 Layers	3.787E-04	2.3124811	5.5 Layers
	9.983E-04	0.2779298	14.5 Layers	3.098E-04	2.6922878	4.5 Layers
	9.295E-04	0.4011113	13.5 Layers	2.410E-04	3.1427365	3.5 Layers
	8.606E-04	0.5507819	12.5 Layer	1.721E-04	3.6946348	2.5 Layers
	7.918E-04	0.7227002	11.5 Layers	1.033E-04	4.2138757	1.5 Layers
	7.229E-04	0.9167283	10.5 Layers	3.442E-05	4.9804912	0.5 Layers
			1.51	Average MeV for Escaping Alphas		
			1.304E+14	Source Particles/second		
			3.702E+11	Particles/sec POTENTIALLY Escaping		
			5.608E+11	MeV/second Escaping		
			5.608E+15	Molecules/second Formed		
			0.2936	Moles / Year per Asbl		
			0.0185	Kilograms /Year per Asbl		

Worksheet for Alpha Particle Transport Calculation Two Hundred Years Cool Time						
Material: UO <sub>2</sub>	Density:	10.4	Radius:	0.4845		
B&W15x15, 4.20w/oU-235		(gram/cc)		(cm)		
48,000 MWD/MTU	Maximum					
Source	Energy	Abundance	Source	Power	Fraction	
(Ci/Asbl)	(MeV)	Fraction	(a/second)	(MeV/s)	of Total P	
U-234	1.19E+00	4.77	1.00	4.403E+10	2.100E+11	0.0003
U-235	8.17E-03	4.58	0.83	2.609E+08	1.149E+09	0.0000
U-238	1.44E-01	4.20	1.00	6.328E+09	2.238E+10	0.0000
Np-237	4.15E-01	4.78	0.87	1.336E+10	6.386E+10	0.0001
Pu-238	6.03E+02	5.60	1.00	2.231E+13	1.227E+14	0.1988
Pu-239	1.87E+02	6.16	0.89	6.850E+12	3.635E+13	0.0573
Pu-240	2.91E+02	5.17	1.00	1.077E+13	5.657E+13	0.0902
Pu-241	5.86E+00	4.80	2.30E-05	4.987E+06	2.444E+07	0.0000
Pu-242	1.34E+00	4.80	1.00	4.958E+10	2.428E+11	0.0004
Am-241	2.26E+03	5.49	0.87	7.276E+13	3.994E+14	0.6470
Am-243	1.86E+01	6.30	1.00	6.682E+11	3.647E+12	0.0059
		Total:	1.135E+14	6.173E+14	1.0000	
		Mean Source Alpha Energy: (MeV)	6.44			
		Maximum Range for Alphas:	1.375E-03			
Pellet Radius:	0.4845					
Range (cm):	1.375E-03					
Non-escape R:	0.4831					
Escape Fraction:	0.0028340	(Half-Space, Portion of the Source which MIGHT Escape))				
Mean Energy:	6.44					
DeltaX: (cm)	6.875E-05					
Number of Steps:	20	(EBAR Values)				
PATH (cm)	1.341E-03	0.0010749	19.6 Layers	6.631E-04	1.1361186	9.6 Layers
	1.272E-03	0.0122760	18.6 Layers	6.844E-04	1.3840900	8.5 Layers
	1.203E-03	0.0431824	17.6 Layers	5.156E-04	1.6549142	7.5 Layers
	1.134E-03	0.0974661	16.6 Layers	4.469E-04	1.9707031	6.5 Layers
	1.066E-03	0.1755306	15.6 Layers	3.781E-04	2.3082012	5.5 Layers
	9.969E-04	0.2766837	14.6 Layers	3.094E-04	2.6877867	4.5 Layers
	9.281E-04	0.3995579	13.6 Layers	2.406E-04	3.1376233	3.5 Layers
	8.594E-04	0.6488954	12.6 Layer	1.718E-04	3.5890958	2.6 Layers
	7.906E-04	0.7205832	11.6 Layers	1.031E-04	4.2078253	1.5 Layers
	7.219E-04	0.9143117	10.6 Layers	3.437E-05	4.9736151	0.6 Layers
			1.61	Average MeV for Escaping Alphas		
			1.135E+14	Source Particles/second		
			3.216E+11	Particles/sec POTENTIALLY Escaping		
			4.862E+11	MeV/second Escaping		
			4.862E+15	Molecules/second Formed		
			0.2545	Moles / Year per Asbl		
			0.0160	Kilograms /Year per Asbl		

Worksheet for Alpha Particle Transport Calculation Two Hundred and Fifty Years Cool Time						
Material: UO2	Density:	10.4	Radius:	0.4845		
B&W15x15, 4.20w/oU-235	(gram/cc)		(cm)			
48,000 MWd/MTU	Maximum					
Source (Ci/Asbl)	Energy (MeV)	Abundance Fraction	Source (a/second)	Power (MeV/s)	Fraction of Total P	
U-234	1.26E+00	4.77	1.00	4.652E+10	2.224E+11	0.0004
U-235	8.17E-03	4.58	0.83	2.609E+08	1.149E+09	0.0000
U-238	1.44E-01	4.20	1.00	5.328E+09	2.238E+10	0.0000
Np-237	4.50E-01	4.78	0.87	1.449E+10	6.924E+10	0.0001
Pu-238	4.07E+02	5.60	1.00	1.506E+13	8.282E+13	0.1514
Pu-239	1.87E+02	5.18	0.99	6.850E+12	3.635E+13	0.0645
Pu-240	2.80E+02	5.17	1.00	1.073E+13	5.547E+13	0.1014
Pu-241	7.88E-01	4.80	2.30E-05	6.706E+05	3.286E+06	0.0000
Pu-242	1.34E+00	4.80	1.00	4.858E+10	2.429E+11	0.0004
Am-241	2.09E+03	6.49	0.87	6.728E+13	3.694E+14	0.6760
Am-243	1.85E+01	6.30	1.00	6.845E+11	3.628E+12	0.0066
		Total:	1.007E+14	5.472E+14	1.0000	
	Mean Source Alpha Energy: (MeV)					5.43
	Maximum Range for Alphas:					1.372E-03
Pellet Radius:	0.4845					
Range (cm):	1.372E-03					
Non-escape R:	0.4831					
Escape Fraction:	0.0028278	(Half-Space, Portion of the Source which MIGHT Escape))				
Mean Energy:	5.43					
DeltaX: (cm)	6.860E-05					
Number of Steps:	20	(EBAR Values)				
PATH (cm)	1.338E-03	0.0011218	19.5 Layers	6.517E-04	1.1351360	9.5 Layers
	1.269E-03	0.0123689	18.5 Layers	5.831E-04	1.3828355	8.5 Layers
	1.200E-03	0.0433718	17.5 Layers	5.145E-04	1.6532905	7.5 Layers
	1.132E-03	0.0976615	16.5 Layers	4.459E-04	1.9686080	6.5 Layers
	1.063E-03	0.1766927	15.5 Layers	3.773E-04	2.3057246	5.5 Layers
	9.947E-04	0.2767821	14.5 Layers	3.087E-04	2.6848535	4.5 Layers
	9.261E-04	0.3995539	13.5 Layers	2.401E-04	3.1339321	3.5 Layers
	8.576E-04	0.6487699	12.5 Layer	1.715E-04	3.6848368	2.5 Layers
	7.889E-04	0.7201709	11.5 Layers	1.029E-04	4.2025937	1.5 Layers
	7.203E-04	0.9136627	10.5 Layers	3.430E-05	4.8673407	0.5 Layers
			1.51	Average MeV for Escaping Alphas		
			1.007E+14	Source Particles/second		
			2.848E+11	Particles/sec POTENTIALLY Escaping		
			4.302E+11	MeV/second Escaping		
			4.302E+15	Molecules/second Formed		
			0.2252	Moles / Year per Asbl		
			0.0142	Kilograms /Year per Asbl		

Worksheet for Alpha Particle Transport Calculation Three Hundred Years Cool Time					
Material: UO2	Density:	10.4	Radius:	0.4845	
B&W15x15, 4.20w/oU-235	(gram/cc)		(cm)		
48,000 MWD/MTU	Maximum				
Source (Ci/Asbl)	Energy (MeV)	Abundance Fraction	Source (a/second)	Power (MeV/s)	Fraction of Total P
U-234	1.31E+00	4.77	1.00	4.847E+10	2.312E+11
U-235	8.18E-03	4.58	0.83	2.612E+08	1.151E+09
U-238	1.44E-01	4.20	1.00	6.328E+09	2.238E+10
Np-237	4.82E-01	4.78	0.87	1.652E+10	7.416E+10
Pu-238	2.75E+02	5.60	1.00	1.018E+13	5.596E+13
Pu-239	1.86E+02	5.16	0.99	6.813E+12	3.516E+13
Pu-240	2.88E+02	5.17	1.00	1.066E+13	5.509E+13
Pu-241	3.33E-01	4.80	2.30E-05	2.834E+05	1.389E+06
Pu-242	1.34E+00	4.80	1.00	4.958E+10	2.429E+11
Am-241	1.93E+03	5.49	0.87	6.213E+13	3.411E+14
Am-243	1.84E+01	5.30	1.00	6.808E+11	3.608E+12
		Total: 9.057E+13		4.915E+14	1.0000
		Mean Source Alpha Energy: (MeV)		5.43	
		Maximum Range for Alphas:		1.370E-03	
Pellet Radius:	0.4845				
Range (cm):	1.370E-03				
Non-escape R:	0.4831				
Escape Fraction:	0.0028237	(Half-Space, Portion of the Source which MIGHT Escape))			
Mean Energy:	6.43				
DeltaX: (cm)	6.650E-05				
Number of Steps:	20	(EBAR Values)			
PATH (cm)	1.336E-03	0.0010915	18.6 Layers	6.507E-04	1.1329413 9.6 Layers
	1.267E-03	0.0122677	18.6 Layers	5.822E-04	1.3802924 8.5 Layers
	1.198E-03	0.0430918	17.6 Layers	5.137E-04	1.8504575 7.6 Layers
	1.130E-03	0.0971924	16.5 Layers	4.452E-04	1.9654109 6.6 Layers
	1.062E-03	0.1750097	15.5 Layers	3.767E-04	2.3021136 5.6 Layers
	9.932E-04	0.2758547	14.5 Layers	3.082E-04	2.6807624 4.6 Layers
	9.247E-04	0.3983887	13.5 Layers	2.397E-04	3.1294773 3.5 Layers
	8.562E-04	0.5473743	12.5 Layer	1.712E-04	3.5709661 2.5 Layers
	7.877E-04	0.7185112	11.5 Layers	1.027E-04	4.1971779 1.5 Layers
	7.192E-04	0.9117396	10.5 Layers	3.425E-05	4.9611311 0.5 Layers
			1.51	Average MeV for Escaping Alphas	
			9.057E+13	Source Particles/second	
			2.557E+11	Particles/sec POTENTIALLY Escaping	
			3.857E+11	MeV/second Escaping	
			3.857E+15	Molecules/second Formed	
			0.2019	Moles / Year per Asbl	
			0.0127	Kilograms /Year per Asbl	

Worksheet for Alpha Particle Transport Calculation Four Hundred Years Cool Time						
Material: UO2	Density:	10.4	Radius:	0.4845		
B&W15x15, 4.20w/oU-235	(gram/cc)			(cm)		
48,000 MWD/MTU	Maximum					
	Source	Abundance	Source	Power	Fraction	
	(Ci/Asbl)	(MeV)	Fraction	(a/second)	(MeV/s)	of Total P
U-234	1.36E+00	4.77	1.00	6.032E+10	2.400E+11	0.0005
U-235	8.20E-03	4.58	0.83	2.518E+08	1.153E+09	0.0000
U-238	1.44E-01	4.20	1.00	6.328E+09	2.238E+10	0.0001
Np-237	5.40E-01	4.78	0.87	1.738E+10	8.309E+10	0.0002
Pu-238	1.26E+02	6.50	1.00	4.662E+12	2.664E+13	0.0626
Pu-239	1.86E+02	6.16	0.99	6.813E+12	3.518E+13	0.0859
Pu-240	2.85E+02	6.17	1.00	1.055E+13	5.452E+13	0.1332
Pu-241	2.87E-01	4.90	2.30E-05	2.442E+05	1.197E+06	0.0000
Pu-242	1.34E+00	4.90	1.00	4.858E+10	2.429E+11	0.0006
Am-241	1.64E+03	5.49	0.87	6.279E+13	2.898E+14	0.7081
Am-243	1.83E+01	6.30	1.00	6.771E+11	3.689E+12	0.0088
		Total:	7.551E+13	4.093E+14	1.0000	
		Mean Source Alpha Energy: (MeV)	5.41			
		Maximum Range for Alphas:	1.365E-03			
Pellet Radius:	0.4845					
Range (cm):	1.365E-03					
Non-escape R:	0.4831					
Escape Fraction:	0.0028134 (Half-Space, Portion of the Source which MIGHT Escape))					
Mean Energy:	5.41					
DeltaX: (cm)	6.825E-05					
Number of Steps:	20 (EBAR Values)					
PATH (cm)	1.331E-03	0.0011296	18.5 Layers	6.484E-04	1.1303006	9.5 Layers
	1.263E-03	0.0123164	18.5 Layers	5.801E-04	1.3770882	8.5 Layers
	1.194E-03	0.0431425	17.5 Layers	5.119E-04	1.6456110	7.5 Layers
	1.126E-03	0.0971293	16.5 Layers	4.436E-04	1.9607428	6.5 Layers
	1.058E-03	0.1747641	15.5 Layers	3.754E-04	2.2967028	5.5 Layers
	9.896E-04	0.2753889	14.5 Layers	3.071E-04	2.6743446	4.5 Layers
	9.214E-04	0.3976272	13.5 Layers	2.389E-04	3.1220146	3.5 Layers
	8.531E-04	0.5461810	12.5 Layer	1.706E-04	3.5715375	2.5 Layers
	7.849E-04	0.7169249	11.5 Layers	1.024E-04	4.1871907	1.5 Layers
	7.166E-04	0.8096892	10.5 Layers	3.412E-05	4.8493408	0.5 Layers
			1.50	Average MeV for Escaping Alphas		
			7.551E+13	Source Particles/second		
			2.127E+11	Particles/sec POTENTIALLY Escaping		
			3.2E+11	MeV/second Escaping		
			3.200E+15	Molecules/second Formed		
			0.1675	Moles / Year per Asbl		
			0.0106	Kilograms /Year per Asbl		

Worksheet for Alpha Particle Transport Calculation Five Hundred Years Cool Time					
Material: UO2	Density:	10.4	Radius:	0.4845	
B&W15x15, 4.20w/oU-235	(gram/cc)		(cm)		
48,000 MWD/MTU	Maximum				
Source	Energy	Abundance	Source	Power	Fraction
(Ci/Asbl)	(MeV)	Fraction	(a/second)	(MeV/s)	of Total P
U-234	1.38E+00	4.77	1.00	5.106E+10	2.436E+11
U-235	8.22E-03	4.68	0.83	2.624E+08	1.156E+09
U-238	1.44E-01	4.20	1.00	6.328E+09	2.238E+10
Np-237	5.69E-01	4.78	0.87	1.896E+10	8.053E+10
Pu-238	6.74E+01	6.60	1.00	2.124E+12	1.168E+13
Pu-239	1.85E+02	5.16	0.89	6.777E+12	3.497E+13
Pu-240	2.82E+02	5.17	1.00	1.043E+13	5.394E+13
Pu-241	2.84E-01	4.90	2.30E-05	2.417E+05	1.184E+06
Pu-242	1.34E+00	4.90	1.00	4.858E+10	2.429E+11
Am-241	1.40E+03	5.49	0.87	4.607E+13	2.474E+14
Am-243	1.81E+01	5.30	1.00	6.697E+11	3.649E+12
		Total:	6.620E+13	3.622E+14	1.0000
		Mean Source Alpha Energy: (MeV)	5.40		
		Maximum Range for Alphas:	1.361E-03		
Pellet Radius:	0.4845				
Range (cm):	1.361E-03				
Non-escape R:	0.4831				
Escape Fraction:	0.0028051	(Half-Space, Portion of the Source which MIGHT Escape))			
Mean Energy:	5.40				
DeltaX: (cm)	6.805E-05				
Number of Steps:	20	(EBAR Values)			
PATH (cm)	1.327E-03	0.0011092	19.5 Layers	6.465E-04	1.1269112 9.5 Layers
	1.259E-03	0.0122186	18.5 Layers	5.784E-04	1.3731158 8.5 Layers
	1.191E-03	0.0428479	17.5 Layers	5.104E-04	1.6420854 7.5 Layers
	1.123E-03	0.0965840	16.5 Layers	4.423E-04	1.9555171 6.5 Layers
	1.055E-03	0.1739163	15.5 Layers	3.743E-04	2.2907607 5.5 Layers
	9.867E-04	0.2741936	14.5 Layers	3.062E-04	2.6677115 4.5 Layers
	9.187E-04	0.3960563	13.5 Layers	2.382E-04	3.1143866 3.5 Layers
	8.506E-04	0.5442142	12.5 Layer	1.701E-04	3.6631067 2.5 Layers
	7.826E-04	0.7145135	11.5 Layers	1.021E-04	4.1776958 1.5 Layers
	7.145E-04	0.9068158	10.5 Layers	3.402E-05	4.8382223 0.5 Layers
		1.50	Average MeV for Escaping Alphas		
		6.620E+13	Source Particles/second		
		1.829E+11	Particles/sec POTENTIALLY Escaping		
		2.744E+11	MeV/second Escaping		
		2.744E+15	Molecules/second Formed		
		0.1437	Moles / Year per Asbl		
		0.0091	Kilograms /Year per Asbl		

Worksheet for Alpha Particle Transport Calculation Six Hundred Years Cool Time						
Material: UO2	Density:	10.4	Radius:	0.4845		
B&W15x15, 4.20w/oU-235	(gram/cc)		(cm)			
48,000 MWD/MTU	Maximum					
Source (Ci/Asbl)	Energy (MeV)	Abundance Fraction	Source (a/second)	Power (MeV/s)	Fraction of Total P	
U-234	1.40E+00	4.77	1.00	5.180E+10	2.471E+11	0.0008
U-235	8.24E-03	4.58	0.83	2.631E+08	1.158E+09	0.0000
U-238	1.44E-01	4.20	1.00	6.328E+09	2.238E+10	0.0001
Np-237	6.31E-01	4.78	0.87	2.031E+10	8.709E+10	0.0003
Pu-238	2.64E+01	5.60	1.00	9.768E+11	6.372E+12	0.0174
Pu-239	1.85E+02	5.16	0.99	6.777E+12	3.497E+13	0.1135
Pu-240	2.79E+02	5.17	1.00	1.032E+13	6.337E+13	0.1732
Pu-241	2.62E-01	4.80	2.30E-05	2.400E+05	1.176E+06	0.0000
Pu-242	1.34E+00	4.80	1.00	4.858E+10	2.428E+11	0.0008
Am-241	1.19E+03	5.49	0.87	3.831E+13	2.103E+14	0.6825
Am-243	1.78E+01	5.30	1.00	6.623E+11	3.610E+12	0.0114
		Total:	5.717E+13	3.081E+14	1.0000	
	Mean Source Alpha Energy: (MeV)					5.39
	Maximum Range for Alphas:					1.357E-03
Pellet Radius:	0.4845					
Range (cm):	1.357E-03					
Non-escape R:	0.4831					
Escape Fraction:	0.0027869	(Half-Space, Portion of the Source which MIGHT Escape))				
Mean Energy:	5.39					
DeltaX: (cm)	6.785E-05					
Number of Steps:	20	(EBAR Values)				
PATH (cm)	1.323E-03	0.0010861	19.5 Layers	6.446E-04	1.1234427	9.5 Layers
	1.255E-03	0.0121166	18.5 Layers	5.767E-04	1.3690639	8.5 Layers
	1.187E-03	0.0425377	17.5 Layers	5.089E-04	1.6374776	7.5 Layers
	1.120E-03	0.0960111	16.5 Layers	4.410E-04	1.9502051	6.5 Layers
	1.052E-03	0.1730362	15.5 Layers	3.732E-04	2.2847025	5.5 Layers
	9.838E-04	0.2729502	14.5 Layers	3.053E-04	2.6609876	4.5 Layers
	9.160E-04	0.3944308	13.5 Layers	2.376E-04	3.1066637	3.5 Layers
	8.481E-04	0.5421915	12.5 Layer	1.696E-04	3.6545747	2.5 Layers
	7.803E-04	0.7120326	11.5 Layers	1.018E-04	4.1679037	1.5 Layers
	7.124E-04	0.9038755	10.5 Layers	3.392E-05	4.8269996	0.5 Layers
		1.50	Average MeV for Escaping Alphas			
		5.717E+13	Source Particles/second			
		1.599E+11	Particles/sec POTENTIALLY Escaping			
		2.393E+11	MeV/second Escaping			
		2.393E+15	Molecules/second Formed			
		0.1253	Moles / Year per Asbl			
		0.0079	Kilograms /Year per Asbl			

Worksheet for Alpha Particle Transport Calculation Seven Hundred Years Cool Time					
Material: UO2	Density:	10.4	Radius:	0.4845	
B&W15x15, 4.20w/oU-235		(gram/cc)		(cm)	
48,000 MWD/MTU	Maximum				
Source (Ci/Asbl)	Energy (MeV)	Abundance Fraction	Source (a/second)	Power (MeV/s)	Fraction of Total P
U-234	1.40E+00	4.77	1.00	5.180E+10	2.471E+11
U-235	8.26E-03	4.58	0.83	2.537E+08	1.162E+09
U-238	1.44E-01	4.20	1.00	5.328E+09	2.238E+10
Np-237	6.67E-01	4.78	0.87	2.147E+10	1.026E+11
Pu-238	1.21E+01	5.60	1.00	4.477E+11	2.462E+12
Pu-239	1.84E+02	5.16	0.89	6.740E+12	3.478E+13
Pu-240	2.76E+02	5.17	1.00	1.021E+13	5.280E+13
Pu-241	2.80E-01	4.90	2.30E-05	2.383E+05	1.168E+06
Pu-242	1.34E+00	4.90	1.00	4.958E+10	2.429E+11
Am-241	1.01E+03	5.49	0.87	3.251E+13	1.785E+14
Am-243	1.78E+01	5.30	1.00	6.586E+11	3.491E+12
		Total:	5.070E+13	2.726E+14	1.0000
		Mean Source Alpha Energy: (MeV)	5.38		
		Maximum Range for Alphas:	1.353E-03		
Pellet Radius:	0.4845				
Range (cm):	1.353E-03				
Non-escape R:	0.4831				
Escape Fraction:	0.0027887	(Half-Space, Portion of the Source which MIGHT Escape))			
Mean Energy:	5.38				
DeltaX: (cm)	6.765E-05				
Number of Steps:	20	(EBAR Values)			
PATH (cm)	1.319E-03	0.0010629	18.5 Layers	6.427E-04	1.1199867
	1.252E-03	0.0120180	18.5 Layers	5.760E-04	1.3650211
	1.184E-03	0.0422302	17.5 Layers	5.074E-04	1.6328745
	1.116E-03	0.0954430	16.5 Layers	4.397E-04	1.8449034
	1.049E-03	0.1721603	15.5 Layers	3.721E-04	2.2786634
	9.809E-04	0.2717176	14.5 Layers	3.044E-04	2.6542718
	9.133E-04	0.3928133	13.5 Layers	2.368E-04	3.0989474
	8.456E-04	0.5401765	12.5 Layer	1.691E-04	3.5460469
	7.780E-04	0.7095595	11.5 Layers	1.015E-04	4.1582135
	7.103E-04	0.9008434	10.5 Layers	3.382E-05	4.8157791
			1.49	Average MeV for Escaping Alphas	
			5.070E+13	Source Particles/second	
			1.414E+11	Particles/sec POTENTIALLY Escaping	
			2.11E+11	MeV/second Escaping	
			2.110E+15	Molecules/second Formed	
			0.1105	Moles / Year per Asbl	
			0.0070	Kilograms /Year per Asbl	

Worksheet for Alpha Particle Transport Calculation Eight Hundred Years Cool Time						
Material: UO2	Density:	10.4	Radius:	0.4845		
B&W15x15, 4.20w/oU-235		(gram/cc)		(cm)		
48,000 MWD/MTU	Maximum					
	Source	Energy	Abundance	Source	Power	Fraction
	(Ci/Asbl)	(MeV)	Fraction	(a/second)	(MeV/s)	of Total P
U-234	1.40E+00	4.77	1.00	6.180E+10	2.471E+11	0.0010
U-235	8.27E-03	4.58	0.83	2.540E+08	1.163E+09	0.0000
U-238	1.44E-01	4.20	1.00	6.328E+09	2.238E+10	0.0001
Np-237	6.97E-01	4.78	0.87	2.244E+10	1.072E+11	0.0004
Pu-238	6.62E+00	5.50	1.00	2.079E+11	1.144E+12	0.0047
Pu-239	1.84E+02	5.16	0.89	6.740E+12	3.478E+13	0.1420
Pu-240	2.73E+02	5.17	1.00	1.010E+13	5.222E+13	0.2132
Pu-241	2.77E-01	4.80	2.30E-05	2.357E+05	1.155E+06	0.0000
Pu-242	1.34E+00	4.80	1.00	4.958E+10	2.429E+11	0.0010
Am-241	6.64E+02	5.49	0.87	2.781E+13	1.527E+14	0.6235
Am-243	1.76E+01	5.30	1.00	6.512E+11	3.451E+12	0.0141
			Total:	4.564E+13	2.449E+14	1.0000
	Mean Source Alpha Energy: (MeV)					5.37
	Maximum Range for Alphas:					1.349E-03
Pellet Radius:	0.4845					
Range (cm):	1.349E-03					
Non-escape R:	0.4832					
Escape Fraction:	0.0027804	(Half-Space, Portion of the Source which MIGHT Escape))				
Mean Energy:	5.37					
DeltaX: (cm)	6.745E-05					
Number of Steps:	20	(EBAR Values)				
PATH (cm)	1.315E-03	0.0010490	19.5 Layers	6.408E-04	1.1167613	9.5 Layers
	1.248E-03	0.0119396	18.5 Layers	5.733E-04	1.3612335	8.5 Layers
	1.180E-03	0.0419841	17.5 Layers	6.059E-04	1.6285323	7.5 Layers
	1.113E-03	0.0949679	16.5 Layers	4.384E-04	1.9398657	6.5 Layers
	1.045E-03	0.1714007	15.5 Layers	3.710E-04	2.2729173	5.5 Layers
	9.780E-04	0.2706354	14.5 Layers	3.035E-04	2.6478238	4.5 Layers
	9.106E-04	0.3913705	13.5 Layers	2.361E-04	3.0915242	3.5 Layers
	8.431E-04	0.6383424	12.5 Layer	1.686E-04	3.5378181	2.5 Layers
	7.757E-04	0.7072949	11.5 Layers	1.012E-04	4.1488055	1.5 Layers
	7.082E-04	0.8982307	10.5 Layers	3.372E-05	4.8048550	0.5 Layers
			1.49	Average MeV for Escaping Alphas		
			4.564E+13	Source Particles/second		
			1.269E+11	Particles/sec POTENTIALLY Escaping		
			1.889E+11	MeV/second Escaping		
			1.889E+15	Molecules/second Formed		
			0.0989	Moles / Year per Asbl		
			0.0062	Kilograms /Year per Asbl		

Worksheet for Alpha Particle Transport Calculation Nine Hundred Years Cool Time					
Material: UO <sub>2</sub>	Density:	10.4	Radius:	0.4845	
B&W15x15, 4.20w/oU-235	(gram/cc)		(cm)		
48,000 MWD/MTU	Maximum				
Source	Energy	Abundance	Source	Power	Fraction
(Ci/Asbl)	(MeV)	Fraction	(a/second)	(MeV/a)	of Total P
U-234	1.40E+00	4.77	1.00	5.180E+10	2.471E+11 0.0011
U-235	8.29E-03	4.58	0.63	2.545E+08	1.156E+09 0.0000
U-238	1.44E-01	4.20	1.00	5.328E+09	2.238E+10 0.0001
Np-237	7.23E-01	4.78	0.67	2.827E+10	1.112E+11 0.0005
Pu-238	2.61E+00	5.60	1.00	9.657E+10	5.311E+11 0.0024
Pu-239	1.83E+02	5.18	0.99	6.703E+12	3.459E+13 0.1565
Pu-240	2.71E+02	5.17	1.00	1.003E+13	5.184E+13 0.2345
Pu-241	2.75E-01	4.90	2.30E-05	2.340E+05	1.147E+06 0.0000
Pu-242	1.34E+00	4.90	1.00	4.858E+10	2.429E+11 0.0011
Am-241	7.36E+02	5.49	0.67	2.369E+13	1.301E+14 0.6884
Am-243	1.74E+01	5.30	1.00	6.438E+11	3.412E+12 0.0154
		Total:	4.129E+13	2.211E+14	1.0000
		Mean Source Alpha Energy: (MeV)	5.35		
		Maximum Range for Alphas:	1.344E-03		
Pellet Radius:	0.4845				
Range (cm):	1.344E-03				
Non-escape R:	0.4832				
Escape Fraction:	0.0027701	(Half-Space, Portion of the Source which MIGHT Escape))			
Mean Energy:	5.35				
DeltaX: (cm)	6.720E-05				
Number of Steps:	20	(EBAR Values)			
PATH (cm)	1.310E-03	0.0011108	19.5 Layers	6.384E-04	1.1147037 9.5 Layers
	1.243E-03	0.0120503	18.5 Layers	5.712E-04	1.3586762 8.5 Layers
	1.176E-03	0.0421921	17.5 Layers	5.040E-04	1.6253432 7.5 Layers
	1.109E-03	0.0951345	16.5 Layers	4.368E-04	1.9358721 6.5 Layers
	1.042E-03	0.1714637	15.5 Layers	3.696E-04	2.2682363 5.5 Layers
	9.744E-04	0.2705412	14.5 Layers	3.024E-04	2.6420826 4.5 Layers
	9.072E-04	0.3910561	13.5 Layers	2.352E-04	3.0847958 3.5 Layers
	8.400E-04	0.5376221	12.5 Layer	1.680E-04	3.5301215 2.5 Layers
	7.728E-04	0.7062308	11.5 Layers	1.008E-04	4.1395046 1.5 Layers
	7.056E-04	0.8967452	10.5 Layers	3.360E-05	4.8937838 0.5 Layers
		1.49	Average MeV for Escaping Alphas		
		4.129E+13	Source Particles/second		
		1.144E+11	Particles/sec POTENTIALLY Escaping		
		1.7E+11	MeV/second Escaping		
		1.700E+15	Molecules/second Formed		
		0.0890	Moles / Year per Asbl		
		0.0056	Kilograms /Year per Asbl		

Worksheet for Alpha Particle Transport Calculation One Thousand Years Cool Time						
Material: UO <sub>2</sub>	Density:	10.4	Radius:	0.4845		
B&W15x15, 4.20w/oU-235		(gram/cc)		(cm)		
48,000 MWD/MTU	Maximum					
Source (Ci/Asbl)	Energy (MeV)	Abundance Fraction	Source (a/second)	Power (MeV/s)	Fraction of Total P	
U-234	1.40E+00	4.77	1.00	6.180E+10	2.471E+11	0.0012
U-235	8.31E-03	4.58	0.83	2.652E+08	1.169E+09	0.0000
U-238	1.44E-01	4.20	1.00	5.328E+09	2.238E+10	0.0001
Np-237	7.45E-01	4.78	0.87	2.398E+10	1.146E+11	0.0006
Pu-238	1.23E+00	6.50	1.00	4.551E+10	2.503E+11	0.0012
Pu-239	1.83E+02	5.16	0.89	6.703E+12	3.458E+13	0.1721
Pu-240	2.68E+02	5.17	1.00	9.918E+12	5.127E+13	0.2551
Pu-241	2.73E-01	4.80	2.30E-05	2.323E+05	1.138E+06	0.0000
Pu-242	1.34E+00	4.80	1.00	4.958E+10	2.428E+11	0.0012
Am-241	6.27E+02	5.49	0.87	2.018E+13	1.108E+14	0.5515
Am-243	1.73E+01	6.30	1.00	6.401E+11	3.393E+12	0.0169
		Total:	3.762E+13	2.009E+14	1.0000	
		Mean Source Alpha Energy: (MeV)	5.34			
		Maximum Range for Alphas:	1.340E-03			
Pellet Radius:	0.4845					
Range (cm):	1.340E-03					
Non-escape R:	0.4832					
Escape Fraction:	0.0027619 (Half-Space, Portion of the Source which MIGHT Escape))					
Mean Energy:	5.34					
DeltaX: (cm)	6.700E-05					
Number of Steps:	20 (EBAR Values)					
PATH (cm)	1.306E-03	0.0010770	18.5 Layers	6.365E-04	1.1109554	9.5 Layers
	1.239E-03	0.0118207	18.5 Layers	6.695E-04	1.3543131	8.5 Layers
	1.172E-03	0.0418127	17.5 Layers	6.025E-04	1.6204081	7.5 Layers
	1.105E-03	0.0944617	16.5 Layers	4.955E-04	1.6302213	6.5 Layers
	1.038E-03	0.1704426	15.5 Layers	3.685E-04	2.2618240	5.5 Layers
	9.715E-04	0.2691293	14.5 Layers	3.015E-04	2.6350140	4.5 Layers
	9.045E-04	0.3892236	13.5 Layers	2.345E-04	3.0766885	3.5 Layers
	8.375E-04	0.5353779	12.5 Layer	1.675E-04	3.5211930	2.5 Layers
	7.705E-04	0.7035050	11.5 Layers	1.005E-04	4.1294262	1.5 Layers
	7.035E-04	0.8935287	10.5 Layers	3.350E-05	4.8821549	0.5 Layers
		1.48	Average MeV for Escaping Alphas			
		3.762E+13	Source Particles/second			
		1.039E+11	Particles/sec POTENTIALLY Escaping			
		1.539E+11	MeV/second Escaping			
		1.539E+15	Molecules/second Formed			
		0.0806	Moles / Year per Asbl			
		0.0051	Kilograms /Year per Asbl			

Alpha Particle Production of Nitric Acid in Waste Package B&W Model 100-2000/48,000 MWD/MTU		
Time (Years)	Moles/Year	kg/Year
5	0.32901	0.02073
100	0.34412	0.02168
150	0.29356	0.01849
200	0.25455	0.01604
250	0.22520	0.01419
300	0.20190	0.01272
400	0.16755	0.01056
500	0.14367	0.00905
600	0.12528	0.00789
700	0.11048	0.00696
800	0.09891	0.00623
900	0.08898	0.00561
1000	0.08059	0.00508
Per Asbl	Per Asbl	
Total (100-1000Y)	139.93	8.8153
Moles/900Y kg/900Y Per 21 Asbl Per 21 Asbl 2938.45 185.12		

## Attachment IV: EXCEL Spreadsheets for 55,000 Mwd/MTU

Worksheet for Alpha Particle Transport Calculation Five Years Cool Time					
Material: UO <sub>2</sub>	Density:	10.4	Radius:	0.4845	
B&W15x15, 5.05w/oU-235		(gram/cc)		(cm)	
55,000 MWD/MTU	Maximum				
	Source	Energy	Abundance	Source	Power
	(Ci/Asbl)	(MeV)	Fraction	(a/second)	(MeV/s)
					Fraction of Total P
U-234	4.80E-01	4.77	1.00	1.813E+10	8.648E+10
U-235	1.02E-02	4.58	0.83	3.132E+08	1.435E+09
U-238	1.46E-01	4.20	1.00	6.402E+09	2.269E+10
Np-237	3.28E-01	4.78	0.87	1.056E+10	5.047E+10
Pu-238	3.75E+03	5.60	1.00	1.388E+14	7.631E+14
Pu-239	2.08E+02	5.16	0.89	7.619E+12	3.831E+13
Pu-240	3.13E+02	5.17	1.00	1.158E+13	5.887E+13
Pu-241	7.72E+04	4.80	2.30E-05	6.670E+10	3.219E+11
Pu-242	1.48E+00	4.80	1.00	6.402E+10	2.647E+11
Am-241	8.35E+02	6.49	0.87	2.688E+13	1.476E+14
Am-243	2.21E+01	6.30	1.00	6.177E+11	4.934E+12
		Total:	1.858E+14	1.015E+15	1.0000
		Mean Source Alpha Energy: (MeV)	6.46		
		Maximum Range for Alphas:	1.383E-03		
Pellet Radius:	0.4845				
Range (cm):	1.383E-03				
Non-escape R:	0.4831				
Escape Fraction:	0.0028504	(Half-Space, Portion of the Source which MIGHT Escape))			
Mean Energy:	6.46				
DeltaX: (cm)	6.015E-05				
Number of Steps:	20	(EBAR Values)			
PATH (cm)	1.348E-03	0.0010867	19.5 Layers	6.669E-04	1.1421425 9.6 Layers
	1.279E-03	0.0123898	18.5 Layers	5.678E-04	1.3911833 8.5 Layers
	1.210E-03	0.0435766	17.5 Layers	5.186E-04	1.6630903 7.5 Layers
	1.141E-03	0.0982719	16.5 Layers	4.495E-04	1.9802446 6.5 Layers
	1.072E-03	0.1768454	15.5 Layers	3.803E-04	2.3191185 5.5 Layers
	1.003E-03	0.2785931	14.5 Layers	3.112E-04	2.7001249 4.5 Layers
	9.335E-04	0.4021350	13.5 Layers	2.420E-04	3.1518462 3.5 Layers
	8.644E-04	0.5523191	12.5 Layer	1.729E-04	3.6049072 2.5 Layers
	7.952E-04	0.7247310	11.5 Layers	1.037E-04	4.2260018 1.5 Layers
	7.261E-04	0.9183184	10.5 Layers	3.457E-05	4.9947842 0.5 Layers
			1.52	Average MeV for Escaping Alphas	
			1.858E+14	Source Particles/second	
			6.206E+11	Particles/sec POTENTIALLY Escaping	
			8.045E+11	MeV/second Escaping	
			8.045E+15	Molecules/second Formed	
			0.4212	Moles / Year per Asbl	
			0.0265	Kilograms /Year per Asbl	

Worksheet for Alpha Particle Transport Calculation One Hundred Years Cool Time						
Material: UO2	Density:	10.4	Radius:	0.4845		
B&W15x15, 5.05w/oU-235	(gram/cc)		(cm)			
55,000 MWD/MTU	Maximum					
	Source (Ci/Asbl)	Energy (MeV)	Abundance Fraction	Source (a/second)	Power (MeV/s)	Fraction of Total P
U-234	1.20E+00	4.77	1.00	4.440E+10	2.118E+11	0.0002
U-235	1.02E-02	4.58	0.83	3.132E+08	1.435E+09	0.0000
U-238	1.46E-01	4.20	1.00	5.402E+09	2.269E+10	0.0000
Np-237	4.10E-01	4.78	0.87	1.320E+10	6.309E+10	0.0001
Pu-238	1.77E+03	5.60	1.00	6.549E+13	3.602E+14	0.3645
Pu-239	2.07E+02	5.16	0.89	7.582E+12	3.913E+13	0.0398
Pu-240	3.18E+02	5.17	1.00	1.177E+13	6.083E+13	0.0616
Pu-241	7.84E+02	4.80	2.30E-05	6.672E+08	3.268E+09	0.0000
Pu-242	1.46E+00	4.80	1.00	5.402E+10	2.647E+11	0.0003
Am-241	2.86E+03	5.49	0.87	8.528E+13	5.231E+14	0.5294
Am-243	2.19E+01	5.30	1.00	8.103E+11	4.295E+12	0.0043
			Total:	1.810E+14	9.681E+14	1.0000
	Mean Source Alpha Energy: (MeV)			5.46		
	Maximum Range for Alphas:			1.381E-03		
Pellet Radius:	0.4845					
Range (cm):	1.381E-03					
Non-escape R:	0.4831					
Escape Fraction:	0.0028463	(Half-Space, Portion of the Source which MIGHT Escape))				
Mean Energy:	5.46					
DeltaX: (cm)	6.805E-05					
Number of Steps:	20	(EBAR Values)				
PATH (cm)	1.346E-03	0.0011087	19.5 Layers	6.560E-04	1.1412614	9.5 Layers
	1.277E-03	0.0124276	18.5 Layers	6.869E-04	1.3900979	8.5 Layers
	1.208E-03	0.0438412	17.5 Layers	5.179E-04	1.6817541	7.5 Layers
	1.139E-03	0.0983137	16.5 Layers	4.488E-04	1.9785876	6.5 Layers
	1.070E-03	0.1768363	15.5 Layers	3.798E-04	2.3171820	5.5 Layers
	1.001E-03	0.2785137	14.5 Layers	3.107E-04	2.6977741	4.5 Layers
	9.322E-04	0.4019613	13.5 Layers	2.417E-04	3.1490976	3.5 Layers
	8.631E-04	0.5519825	12.5 Layer	1.726E-04	3.6017774	2.5 Layers
	7.941E-04	0.7242532	11.5 Layers	1.036E-04	4.2222389	1.5 Layers
	7.250E-04	0.9186694	10.5 Layers	3.452E-05	4.8903137	0.5 Layers
			Average MeV for Escaping Alphas	1.52		
			Source Particles/second	1.810E+14		
			Particles/sec POTENTIALLY Escaping	5.153E+11		
			MeV/second Escaping	7.822E+11		
			Molecules/second Formed	7.822E+15		
			Moles / Year per Asbl	0.4095		
			Kilograms /Year per Asbl	0.0258		

Worksheet for Alpha Particle Transport Calculation One Hundred and Fifty Years Cool Time						
Material: UO <sub>2</sub>	Density:	10.4	Radius:	0.4845		
B&W15x15, 5.05w/oU-235	(gram/cc)		(cm)			
55,000 MWd/MTU	Maximum					
	Source	Energy	Abundance	Source	Power	Fraction
	(Ci/Asbl)	(MeV)	Fraction	(a/second)	(MeV/s)	of Total P
U-234	1.40E+00	4.77	1.00	6.180E+10	2.471E+11	0.0003
U-235	1.02E-02	4.58	0.83	3.132E+08	1.435E+09	0.0000
U-238	1.46E-01	4.20	1.00	6.402E+09	2.269E+10	0.0000
Np-237	4.56E-01	4.78	0.87	1.468E+10	7.016E+10	0.0001
Pu-238	1.20E+03	5.50	1.00	4.440E+13	2.442E+14	0.2920
Pu-239	2.07E+02	5.16	0.99	7.682E+12	3.913E+13	0.0468
Pu-240	3.16E+02	5.17	1.00	1.168E+13	6.045E+13	0.0723
Pu-241	7.04E+01	4.90	2.30E-05	5.891E+07	2.836E+08	0.0000
Pu-242	1.46E+00	4.90	1.00	6.402E+10	2.647E+11	0.0003
Am-241	2.76E+03	5.49	0.87	8.884E+13	4.878E+14	0.5832
Am-243	2.18E+01	5.30	1.00	8.066E+11	4.275E+12	0.0051
		Total:	1.635E+14	8.364E+14	1.0000	
	Mean Source Alpha Energy: (MeV)					5.45
	Maximum Range for Alphas:					1.379E-03
Pellet Radius:	0.4845					
Range (cm):	1.379E-03					
Non-escape R:	0.4831					
Escape Fraction:	0.0028422	(Half-Space, Portion of the Source which MIGHT Escape))				
Mean Energy:	5.45					
DeltaX: (cm)	6.895E-05					
Number of Steps:	20	(EBAR Values)				
PATH (cm)	1.345E-03	0.0010610	19.5 Layers	6.650E-04	1.1386432	9.5 Layers
	1.276E-03	0.0122808	18.5 Layers	5.861E-04	1.3870989	8.5 Layers
	1.207E-03	0.0432500	17.5 Layers	5.171E-04	1.6584535	7.5 Layers
	1.138E-03	0.0976790	16.5 Layers	4.482E-04	1.9749080	6.5 Layers
	1.069E-03	0.1759366	15.5 Layers	3.792E-04	2.3130437	5.5 Layers
	9.998E-04	0.2773277	14.5 Layers	3.103E-04	2.6933865	4.5 Layers
	9.308E-04	0.4004780	13.5 Layers	2.413E-04	3.1441089	3.5 Layers
	8.619E-04	0.5502696	12.5 Layer	1.724E-04	3.5963647	2.5 Layers
	7.929E-04	0.7222211	11.5 Layers	1.034E-04	4.2163099	1.5 Layers
	7.240E-04	0.9163466	10.5 Layers	3.447E-05	4.9835665	0.5 Layers
			1.62	Average MeV for Escaping Alphas		
			1.635E+14	Source Particles/second		
			4.361E+11	Particles/sec POTENTIALLY Escaping		
			6.608E+11	MeV/second Escaping		
			6.608E+15	Molecules/second Formed		
			0.3459	Moles / Year per Asbl		
			0.0218	Kilograms /Year per Asbl		

Worksheet for Alpha Particle Transport Calculation Two Hundred Years Cool Time					
Material: UO2	Density:	10.4	Radius:	0.4845	
B&W15x15, 5.05w/oU-235	(gram/cc)		(cm)		
55,000 MWD/MTU	Maximum				
Source (Ci/Asbl)	Energy (MeV)	Abundance Fraction	Source (a/second)	Power (MeV/s)	Fraction of Total P
U-234	1.54E+00	4.77	1.00	6.698E+10	2.718E+11
U-235	1.02E-02	4.68	0.83	3.132E+08	1.435E+09
U-238	1.46E-01	4.20	1.00	5.402E+09	2.269E+10
Np-237	4.99E-01	4.78	0.87	1.606E+10	7.678E+10
Pu-238	8.07E+02	5.60	1.00	2.886E+13	1.642E+14
Pu-239	2.07E+02	5.16	0.99	7.582E+12	3.913E+13
Pu-240	3.15E+02	5.17	1.00	1.166E+13	6.026E+13
Pu-241	6.65E+00	4.90	2.30E-05	5.658E+06	2.773E+07
Pu-242	1.48E+00	4.90	1.00	5.402E+10	2.647E+11
Am-241	2.65E+03	5.49	0.87	8.208E+13	4.508E+14
Am-243	2.16E+01	5.30	1.00	7.892E+11	4.236E+12
		Total:	1.321E+14	7.191E+14	1.0000
		Mean Source Alpha Energy: (MeV)	5.44		
		Maximum Range for Alphas:	1.376E-03		
Pellet Radius:	0.4845				
Range (cm):	1.376E-03				
Non-escape R:	0.4831				
Escape Fraction:	0.0028360	(Half-Space, Portion of the Source which MIGHT Escape))			
Mean Energy:	5.44				
DeltaX: (cm)	6.880E-05				
Number of Steps:	20	(EBAR Values)			
PATH (cm)	1.342E-03	0.0010941	19.5 Layers	6.636E-04	1.1373159 9.5 Layers
	1.273E-03	0.0123372	18.5 Layers	5.848E-04	1.3854880 8.5 Layers
	1.204E-03	0.0433483	17.5 Layers	5.180E-04	1.6564427 7.5 Layers
	1.135E-03	0.0977400	16.5 Layers	4.472E-04	1.9724158 6.5 Layers
	1.066E-03	0.1769223	15.5 Layers	3.784E-04	2.3101315 5.5 Layers
	9.976E-04	0.27772064	14.5 Layers	3.086E-04	2.6898527 4.5 Layers
	9.288E-04	0.4002157	13.5 Layers	2.408E-04	3.1389770 3.5 Layers
	8.600E-04	0.5497645	12.5 Layer	1.720E-04	3.6916589 2.5 Layers
	7.912E-04	0.7215008	11.5 Layers	1.032E-04	4.2106548 1.5 Layers
	7.224E-04	0.9153685	10.5 Layers	3.440E-05	4.9768473 0.5 Layers
			1.51	Average MeV for Escaping Alphas	
			1.321E+14	Source Particles/second	
			3.747E+11	Particles/sec POTENTIALLY Escaping	
			5.67E+11	MeV/second Escaping	
			5.670E+15	Molecules/second Formed	
			0.2968	Moles / Year per Asbl	
			0.0187	Kilograms /Year per Asbl	

Worksheet for Alpha Particle Transport Calculation Two Hundred and Fifty Years Cool Time						
Material: UO2	Density:	10.4	Radius:	0.4845		
B&W15x15, 6.05w/oU-235	(gram/cc)		(cm)			
55,000 MWD/MTU	Maximum					
Source (Ci/Asbl)	Energy (MeV)	Abundance Fraction	Source (a/second)	Power (MeV/s)	Fraction of Total P	
U-234	1.64E+00	4.77	1.00	6.068E+10	2.694E+11	0.0005
U-235	1.02E-02	4.58	0.83	3.132E+08	1.435E+09	0.0000
U-238	1.46E-01	4.20	1.00	6.402E+09	2.269E+10	0.0000
Np-237	5.39E-01	4.78	0.87	1.735E+10	8.293E+10	0.0001
Pu-238	6.45E+02	5.50	1.00	2.017E+13	1.109E+14	0.1761
Pu-239	2.06E+02	5.18	0.89	7.548E+12	3.894E+13	0.0618
Pu-240	3.13E+02	5.17	1.00	1.158E+13	6.987E+13	0.0951
Pu-241	9.58E-01	4.90	2.30E-05	8.153E+05	3.895E+06	0.0000
Pu-242	1.46E+00	4.90	1.00	6.402E+10	2.647E+11	0.0004
Am-241	2.35E+03	6.49	0.87	7.565E+13	4.153E+14	0.6593
Am-243	2.15E+01	6.30	1.00	7.955E+11	4.216E+12	0.0067
		Total:	1.159E+14	6.299E+14	1.0000	
		Mean Source Alpha Energy: (MeV)	5.44			
		Maximum Range for Alphas:	1.373E-03			
Pellet Radius:	0.4845					
Range (cm):	1.373E-03					
Non-escape R:	0.4831					
Escape Fraction:	0.0028298	(Half-Space, Portion of the Source which MIGHT Escape))				
Mean Energy:	5.44					
DeltaX: (cm)	6.865E-05					
Number of Steps:	20	(EBAR Values)				
PATH (cm)	1.339E-03	0.0011369	19.5 Layers	6.622E-04	1.1362267	9.6 Layers
	1.270E-03	0.0124189	18.5 Layers	5.835E-04	1.3840974	8.6 Layers
	1.201E-03	0.0435098	17.5 Layers	5.149E-04	1.6546985	7.6 Layers
	1.133E-03	0.0978935	16.5 Layers	4.462E-04	1.9701975	6.6 Layers
	1.064E-03	0.1760303	15.5 Layers	3.776E-04	2.3076200	5.6 Layers
	9.954E-04	0.2772368	14.5 Layers	3.089E-04	2.6865952	4.6 Layers
	9.268E-04	0.4001315	13.5 Layers	2.403E-04	3.1361492	3.6 Layers
	8.581E-04	0.5494455	12.5 Layer	1.716E-04	3.5872617	2.6 Layers
	7.895E-04	0.7209831	11.5 Layers	1.030E-04	4.2052914	1.6 Layers
	7.208E-04	0.9146174	10.5 Layers	3.432E-05	4.8704347	0.6 Layers
			1.51	Average MeV for Escaping Alphas		
			1.159E+14	Source Particles/second		
			3.279E+11	Particles/sec POTENTIALLY Escaping		
			4.856E+11	MeV/second Escaping		
			4.856E+15	Molecules/second Formed		
			0.2595	Moles / Year per Asbl		
			0.0163	Kilograms /Year per Asbl		

Worksheet for Alpha Particle Transport Calculation Three Hundred Years Cool Time						
Material: UO2	Density:	10.4	Radius:	0.4845		
B&W15x15, 6.05w/oU-235	(gram/cc)		(cm)			
55,000 MWD/MTU	Maximum					
Source (Ci/Asbl)	Energy (MeV)	Abundance Fraction	Source (a/second)	Power (MeV/s)	Fraction of Total P	
U-234	1.70E+00	4.77	1.00	6.290E+10	3.000E+11	0.0005
U-235	1.02E-02	4.58	0.83	3.132E+08	1.435E+09	0.0000
U-238	1.46E-01	4.20	1.00	6.402E+09	2.269E+10	0.0000
Np-237	5.75E-01	4.78	0.87	1.851E+10	6.847E+10	0.0002
Pu-238	3.68E+02	5.60	1.00	1.362E+13	7.489E+13	0.1333
Pu-239	2.06E+02	5.16	0.89	7.546E+12	3.894E+13	0.0693
Pu-240	3.11E+02	5.17	1.00	1.151E+13	5.849E+13	0.1059
Pu-241	4.48E-01	4.90	2.30E-05	3.812E+05	1.868E+06	0.0000
Pu-242	1.45E+00	4.90	1.00	6.402E+10	2.647E+11	0.0005
Am-241	2.17E+03	5.49	0.87	6.985E+13	3.835E+14	0.6828
Am-243	2.14E+01	5.30	1.00	7.918E+11	4.197E+12	0.0076
		Total:	1.035E+14	5.617E+14	1.0000	
		Mean Source Alpha Energy: (MeV)	5.43			
		Maximum Range for Alphas:	1.371E-03			
Pellet Radius:	0.4845					
Range (cm):	1.371E-03					
Non-escape R:	0.4831					
Escape Fraction:	0.0028257	(Half-Space, Portion of the Source which MIGHT Escape))				
Mean Energy:	5.43					
DeltaX: (cm)	6.855E-05					
Number of Steps:	20 (EBAR Values)					
PATH (cm)	1.337E-03	0.0010958	19.5 Layers	6.612E-04	1.1337661	9.5 Layers
	1.268E-03	0.0122894	18.5 Layers	5.827E-04	1.3812625	8.5 Layers
	1.200E-03	0.0431599	17.5 Layers	5.141E-04	1.6515642	7.5 Layers
	1.131E-03	0.0973208	16.5 Layers	4.458E-04	1.9666915	6.5 Layers
	1.063E-03	0.1752116	15.5 Layers	3.770E-04	2.3035730	5.5 Layers
	9.940E-04	0.2761494	14.5 Layers	3.085E-04	2.6823825	4.5 Layers
	9.254E-04	0.3987652	13.5 Layers	2.399E-04	3.1313527	3.5 Layers
	8.569E-04	0.5478498	12.5 Layer	1.714E-04	3.6820426	2.5 Layers
	7.883E-04	0.7180863	11.5 Layers	1.028E-04	4.1995454	1.5 Layers
	7.198E-04	0.8124372	10.5 Layers	3.427E-05	4.8638781	0.5 Layers
		1.51	Average MeV for Escaping Alphas			
		1.035E+14	Source Particles/second			
		2.823E+11	Particles/sec POTENTIALLY Escaping			
		4.411E+11	MeV/second Escaping			
		4.411E+15	Molecules/second Formed			
		0.2309	Moles / Year per Asbl			
		0.0145	Kilograms /Year per Asbl			

Worksheet for Alpha Particle Transport Calculation Four Hundred Years Cool Time					
Material: UO <sub>2</sub>	Density:	10.4	Radius:	0.4845	
B&W15x15, 6.05w/oU-235		(gram/cc)		(cm)	
55,000 MWD/MTU	Maximum				
	Source	Energy	Abundance	Source	Power
	(Ci/Asbl)	(MeV)	Fraction	(s/second)	(MeV/s)
					Fraction of Total P
U-234	1.77E+00	4.77	1.00	6.649E+10	3.124E+11
U-235	1.02E-02	4.58	0.83	3.132E+08	1.435E+09
U-238	1.45E-01	4.20	1.00	6.402E+09	2.269E+10
Np-237	6.40E-01	4.78	0.87	2.060E+10	8.848E+10
Pu-238	1.68E+02	5.50	1.00	6.216E+12	3.419E+13
Pu-239	2.06E+02	5.16	0.99	7.645E+12	3.694E+13
Pu-240	3.08E+02	5.17	1.00	1.140E+13	5.892E+13
Pu-241	3.95E-01	4.90	2.30E-05	3.361E+05	1.647E+06
Pu-242	1.46E+00	4.90	1.00	6.402E+10	2.647E+11
Am-241	1.85E+03	5.49	0.87	6.855E+13	3.269E+14
Am-243	2.12E+01	5.30	1.00	7.844E+11	4.157E+12
			Total:	8.664E+13	4.638E+14
					1.0000
			Mean Source Alpha Energy: (MeV)	5.42	
			Maximum Range for Alphas:	1.366E-03	
Pellet Radius:	0.4845				
Range (cm):	1.366E-03				
Non-escape R:	0.4831				
Escape Fraction:	0.0028154	(Half-Space, Portion of the Source which MIGHT Escape))			
Mean Energy:	5.42				
DeltaX: (cm)	6.630E-05				
Number of Steps:	20	(EBAR Values)			
PATH (cm)	1.332E-03	0.0011266	19.5 Layers	6.488E-04	1.1309436 9.5 Layers
	1.264E-03	0.0123187	18.5 Layers	5.805E-04	1.3778559 8.5 Layers
	1.195E-03	0.0431625	17.5 Layers	5.122E-04	1.6475109 7.5 Layers
	1.127E-03	0.0971865	16.5 Layers	4.439E-04	1.9618107 6.5 Layers
	1.059E-03	0.1748717	15.5 Layers	3.756E-04	2.2979312 5.5 Layers
	9.903E-04	0.2755576	14.5 Layers	3.073E-04	2.6757615 4.5 Layers
	9.220E-04	0.3978655	13.5 Layers	2.390E-04	3.1236567 3.5 Layers
	8.537E-04	0.5465109	12.5 Layer	1.707E-04	3.5733750 2.5 Layers
	7.854E-04	0.7173445	11.5 Layers	1.024E-04	4.1893324 1.5 Layers
	7.171E-04	0.9102102	10.5 Layers	3.415E-05	4.9518506 0.5 Layers
			1.51	Average MeV for Escaping Alphas	
			8.664E+13	Source Particles/second	
			2.411E+11	Particles/sec POTENTIALLY Escaping	
			3.629E+11	MeV/second Escaping	
			3.629E+15	Molecules/second Formed	
			0.1800	Moles / Year per Asbl	
			0.0120	Kilograms /Year per Asbl	

Worksheet for Alpha Particle Transport Calculation Five Hundred Years Cool Time						
Material: UO <sub>2</sub>	Density:	10.4	Radius:	0.4845		
B&W15x15, 5.05w/oU-235	(gram/cc)		(cm)			
55,000 MWD/MTU	Maximum					
	Source	Energy	Abundance	Source	Power	Fraction
	(Ci/Asbl)	(MeV)	Fraction	(a/second)	(MeV/s)	of Total P
U-234	1.80E+00	4.77	1.00	6.660E+10	3.177E+11	0.0008
U-235	1.03E-02	4.58	0.83	3.163E+08	1.449E+09	0.0000
U-238	1.46E-01	4.20	1.00	5.402E+09	2.269E+10	0.0001
Np-237	6.86E-01	4.78	0.87	2.240E+10	1.071E+11	0.0003
Pu-238	7.68E+01	5.60	1.00	2.842E+12	1.663E+13	0.0384
Pu-239	2.05E+02	5.16	0.89	7.509E+12	3.875E+13	0.0977
Pu-240	3.05E+02	5.17	1.00	1.129E+13	5.834E+13	0.1470
Pu-241	3.91E-01	4.80	2.30E-05	3.327E+05	1.630E+06	0.0000
Pu-242	1.45E+00	4.80	1.00	5.402E+10	2.647E+11	0.0007
Am-241	1.58E+03	5.49	0.87	6.086E+13	2.792E+14	0.7037
Am-243	2.10E+01	6.30	1.00	7.770E+11	4.118E+12	0.0104
			Total:	7.342E+13	3.068E+14	1.0000
			Mean Source Alpha Energy: (MeV)	5.40		
			Maximum Range for Alphas:	1.362E-03		
Pellet Radius:	0.4845					
Range (cm):	1.362E-03					
Non-escape R:	0.4831					
Escape Fraction:	0.0028072	(Half-Space, Portion of the Source which MIGHT Escape))				
Mean Energy:	5.40					
DeltaX: (cm)	6.610E-05					
Number of Steps:	20	(EBAR Values)				
PATH (cm)	1.328E-03	0.0010992	19.5 Layers	6.489E-04	1.1273812	9.5 Layers
	1.260E-03	0.0122037	18.5 Layers	5.788E-04	1.3736903	8.5 Layers
	1.192E-03	0.0428219	17.5 Layers	5.107E-04	1.8427870	7.5 Layers
	1.124E-03	0.0965734	16.5 Layers	4.426E-04	1.9563818	6.5 Layers
	1.056E-03	0.1739340	15.5 Layers	3.745E-04	2.2917589	5.5 Layers
	9.874E-04	0.2742511	14.5 Layers	3.064E-04	2.6689250	4.5 Layers
	9.193E-04	0.3961642	13.5 Layers	2.383E-04	3.1158038	3.5 Layers
	8.612E-04	0.6444044	12.5 Layer	1.702E-04	3.5647164	2.5 Layers
	7.831E-04	0.7147772	11.5 Layers	1.021E-04	4.1785221	1.5 Layers
	7.150E-04	0.9071683	10.5 Layers	3.405E-05	4.8405059	0.5 Layers
			1.50	Average MeV for Escaping Alphas		
			7.342E+13	Source Particles/second		
			2.061E+11	Particles/sec POTENTIALLY Escaping		
			3.094E+11	MeV/second Escaping		
			3.094E+15	Molecules/second Formed		
			0.1620	Moles / Year per Asbl		
			0.0102	Kilograms /Year per Asbl		

Worksheet for Alpha Particle Transport Calculation Six Hundred Years Cool Time						
Material: UO2	Density:	10.4	Radius:	0.4845		
B&W15x15, 5.05w/oU-235.	(gram/cc)		(cm)			
55,000 MWD/MTU	Maximum					
	Source	Energy	Abundance	Source	Power	Fraction
	(Ci/Asbl)	(MeV)	Fraction	(a/second)	(MeV/s)	of Total P
U-234	1.82E+00	4.77	1.00	6.734E+10	3.212E+11	0.0009
U-235	1.03E-02	4.68	0.83	3.163E+08	1.449E+09	0.0000
U-238	1.45E-01	4.20	1.00	5.402E+09	2.269E+10	0.0001
Np-237	7.43E-01	4.78	0.87	2.392E+10	1.143E+11	0.0003
Pu-238	3.62E+01	5.60	1.00	1.302E+12	7.163E+12	0.0207
Pu-239	2.05E+02	5.16	0.99	7.609E+12	3.876E+13	0.1122
Pu-240	3.02E+02	5.17	1.00	1.117E+13	5.777E+13	0.1673
Pu-241	3.88E-01	4.90	2.30E-05	3.302E+05	1.618E+06	0.0000
Pu-242	1.45E+00	4.90	1.00	5.402E+10	2.647E+11	0.0008
Am-241	1.34E+03	5.49	0.87	4.313E+13	2.368E+14	0.6858
Am-243	2.09E+01	5.30	1.00	7.733E+11	4.098E+12	0.0119
			Total:	6.404E+13	3.453E+14	1.0000
			Mean Source Alpha Energy: (MeV)	5.39		
			Maximum Range for Alphas:	1.358E-03		
Pellet Radius:	0.4845					
Range (cm):	1.358E-03					
Non-escape R:	0.4831					
Escape Fraction:	0.0027890	(Half-Space, Portion of the Source which MIGHT Escape))				
Mean Energy:	5.39					
DeltaX: (cm)	6.790E-05					
Number of Steps:	20	(EBAR Values)				
PATH (cm)	1.324E-03	0.0010667	19.5 Layers	6.450E-04	1.1236769	9.5 Layers
	1.256E-03	0.0120769	18.5 Layers	5.771E-04	1.3693784	8.5 Layers
	1.188E-03	0.0424500	17.5 Layers	5.092E-04	1.6379115	7.5 Layers
	1.120E-03	0.0959084	16.5 Layers	4.413E-04	1.9507938	6.5 Layers
	1.052E-03	0.1729330	15.5 Layers	3.734E-04	2.2854112	5.5 Layers
	8.845E-04	0.2728567	14.5 Layers	3.055E-04	2.6619238	4.5 Layers
	8.166E-04	0.3943599	13.5 Layers	2.376E-04	3.1077756	3.5 Layers
	8.487E-04	0.5421933	12.5 Layer	1.697E-04	3.5558750	2.5 Layers
	7.808E-04	0.7120846	11.5 Layers	1.018E-04	4.1695360	1.5 Layers
	7.129E-04	0.9039996	10.5 Layers	3.395E-05	4.8289743	0.5 Layers
			1.50	Average MeV for Escaping Alphas		
			6.404E+13	Source Particles/second		
			1.793E+11	Particles/sec POTENTIALLY Escaping		
			2.684E+11	MeV/second Escaping		
			2.684E+15	Molecules/second Formed		
			0.1405	Moles / Year per Asbl		
			0.0089	Kilograms /Year per Asbl		

Worksheet for Alpha Particle Transport Calculation Seven Hundred Years Cool Time						
Material: UO <sub>2</sub>	Density:	10.4	Radius:	0.4845		
B&W15x15, 5.05w/oU-235		(gram/cc)		(cm)		
55,000 MWD/MTU	Maximum					
Source (Ci/Asbl)	Energy (MeV)	Abundance Fraction	Source (a/second)	Power (MeV/s)	Fraction of Total P	
U-234	1.82E+00	4.77	1.00	6.734E+10	3.212E+11	0.0011
U-235	1.03E-02	4.58	0.83	3.163E+08	1.449E+09	0.0000
U-238	1.46E-01	4.20	1.00	5.402E+09	2.269E+10	0.0001
Np-237	7.83E-01	4.78	0.87	2.620E+10	1.205E+11	0.0004
Pu-238	1.62E+01	6.50	1.00	5.894E+11	3.297E+12	0.0108
Pu-239	2.04E+02	6.16	0.89	7.473E+12	3.856E+13	0.1263
Pu-240	2.89E+02	6.17	1.00	1.106E+13	5.720E+13	0.1873
Pu-241	3.85E-01	4.80	2.30E-05	3.276E+05	1.605E+06	0.0000
Pu-242	1.46E+00	4.80	1.00	5.402E+10	2.647E+11	0.0009
Am-241	1.14E+03	5.49	0.87	3.670E+13	2.015E+14	0.6599
Am-243	2.07E+01	5.30	1.00	7.659E+11	4.059E+12	0.0133
		Total:	6.675E+13	3.053E+14	1.0000	
		Mean Source Alpha Energy: (MeV)	5.38			
		Maximum Range for Alphas:	1.354E-03			
Pellet Radius:	0.4845					
Range (cm):	1.354E-03					
Non-escape R:	0.4831					
Escape Fraction:	0.0027807 (Half-Space, Portion of the Source which MIGHT Escape))					
Mean Energy:	5.38					
DeltaX: (cm)	6.770E-05					
Number of Steps:	20 (EBAR Values)					
PATH (cm)	1.320E-03	0.0010463	19.5 Layers	6.431E-04	1.1202908	9.5 Layers
	1.252E-03	0.0119828	18.5 Layers	5.754E-04	1.3654145	8.5 Layers
	1.185E-03	0.0421611	17.5 Layers	5.077E-04	1.6333914	7.5 Layers
	1.117E-03	0.0953686	16.5 Layers	4.400E-04	1.9455769	6.5 Layers
	1.049E-03	0.1720936	15.5 Layers	3.723E-04	2.2704625	5.5 Layers
	9.816E-04	0.2716687	14.5 Layers	3.046E-04	2.6552925	4.5 Layers
	9.139E-04	0.3927959	13.5 Layers	2.369E-04	3.1001528	3.5 Layers
	8.462E-04	0.5402348	12.5 Layer	1.692E-04	3.5474425	2.5 Layers
	7.785E-04	0.7096767	11.5 Layers	1.015E-04	4.1599365	1.5 Layers
	7.108E-04	0.9011361	10.5 Layers	3.385E-05	4.9178494	0.5 Layers
			1.49	Average MeV for Escaping Alphas		
			6.675E+13	Source Particles/second		
			1.584E+11	Particles/sec POTENTIALLY Escaping		
			2.365E+11	MeV/second Escaping		
			2.365E+15	Molecules/second Formed		
			0.1238	Moles / Year per Asbl		
			0.0078	Kilograms /Year per Asbl		

Worksheet for Alpha Particle Transport Calculation Eight Hundred Years Cool Time					
Material: UO <sub>2</sub>	Density:	10.4	Radius:	0.4845	
B&W15x15, 5.05w/oU-235	(gram/cc)		(cm)		
55,000 MWD/MTU	Maximum				
Source (Cl/Asbl)	Energy (MeV)	Abundance Fraction	Source (e/second)	Power (MeV/s)	Fraction of Total P
U-234	1.83E+00	4.77	1.00	6.771E+10	3.230E+11
U-235	1.03E-02	4.58	0.83	3.163E+08	1.449E+09
U-238	1.46E-01	4.20	1.00	5.402E+09	2.269E+10
Np-237	8.17E-01	4.78	0.87	2.630E+10	1.257E+11
Pu-238	7.51E+00	5.50	1.00	2.770E+11	1.528E+12
Pu-239	2.04E+02	5.16	0.89	7.473E+12	3.856E+13
Pu-240	2.85E+02	5.17	1.00	1.092E+13	6.643E+13
Pu-241	3.82E-01	4.90	2.30E-05	3.251E+05	1.593E+06
Pu-242	1.46E+00	4.90	1.00	5.402E+10	2.647E+11
Am-241	9.75E+02	6.49	0.87	3.139E+13	1.723E+14
Am-243	2.05E+01	6.30	1.00	7.585E+11	4.020E+12
		Total:	5.096E+13	2.738E+14	1.0000
	Mean Source Alpha Energy: (MeV)		5.37		
	Maximum Range for Alphas:		1.350E-03		
Pellet Radius:	0.4845				
Range (cm):	1.350E-03				
Non-escape R:	0.4832				
Escape Fraction:	0.0027825	(Half-Space, Portion of the Source which MIGHT Escape))			
Mean Energy:	5.37				
DeltaX: (cm)	6.760E-05				
Number of Steps:	20	(EBAR Values)			
PATH (cm)	1.316E-03	0.0010351	19.5 Layers	6.412E-04	1.1171321 9.5 Layers
	1.249E-03	0.0119133	18.5 Layers	5.737E-04	1.3616997 8.5 Layers
	1.181E-03	0.0419321	17.5 Layers	5.062E-04	1.6291240 7.5 Layers
	1.114E-03	0.0949188	16.5 Layers	4.387E-04	1.9406165 6.5 Layers
	1.046E-03	0.1713576	15.5 Layers	3.712E-04	2.2738012 5.5 Layers
	9.787E-04	0.2706286	14.5 Layers	3.037E-04	2.6489237 4.5 Layers
	9.112E-04	0.3914027	13.5 Layers	2.362E-04	3.0928163 3.5 Layers
	8.437E-04	0.5384537	12.5 Layer	1.687E-04	3.5393004 2.5 Layers
	7.762E-04	0.7074714	11.5 Layers	1.012E-04	4.1506134 1.5 Layers
	7.087E-04	0.8984870	10.5 Layers	3.376E-05	4.8070143 0.5 Layers
			1.49	Average MeV for Escaping Alphas	
			5.096E+13	Source Particles/second	
			1.418E+11	Particles/sec POTENTIALLY Escaping	
			2.112E+11	MeV/second Escaping	
			2.112E+15	Molecules/second Formed	
			0.1106	Moles / Year per Asbl	
			0.0070	Kilograms /Year per Asbl	

Worksheet for Alpha Particle Transport Calculation Nine Hundred Years Cool Time						
Material: UO2	Density:	10.4	Radius:	0.4845		
B&W15x15, 6.05w/oU-235	(gram/cc)		(cm)			
55,000 MWD/MTU	Maximum					
	Source (Ci/Asbl)	Energy (MeV)	Abundance Fraction	Source (s/second)	Power (MeV/s)	Fraction of Total P
U-234	1.83E+00	4.77	1.00	6.771E+10	3.230E+11	0.0013
U-235	1.03E-02	4.58	0.83	3.163E+08	1.449E+09	0.0000
U-238	1.45E-01	4.20	1.00	5.402E+09	2.269E+10	0.0001
Np-237	6.45E-01	4.78	0.87	2.723E+10	1.302E+11	0.0005
Pu-238	3.49E+00	5.50	1.00	1.291E+11	7.102E+11	0.0029
Pu-239	2.03E+02	5.16	0.99	7.436E+12	3.837E+13	0.1558
Pu-240	2.82E+02	5.17	1.00	1.080E+13	5.586E+13	0.2267
Pu-241	3.79E-01	4.80	2.30E-05	3.225E+05	1.680E+06	0.0000
Pu-242	1.46E+00	4.80	1.00	5.402E+10	2.647E+11	0.0011
Am-241	8.30E+02	5.49	0.87	2.672E+13	1.457E+14	0.5954
Am-243	2.03E+01	5.30	1.00	7.611E+11	3.981E+12	0.0162
			Total:	4.699E+13	2.463E+14	1.0000
	Mean Source Alpha Energy: (MeV)			5.36		
	Maximum Range for Alphas:			1.345E-03		
Pellet Radius:	0.4845					
Range (cm):	1.345E-03					
Non-escape R:	0.4832					
Escape Fraction:	0.0027722	(Half-Space, Portion of the Source which MIGHT Escape))				
Mean Energy:	6.36					
DeltaX: (cm)	6.725E-05					
Number of Steps:	20	(EBAR Values)				
PATH (cm)	1.311E-03	0.0010991	18.5 Layers	6.389E-04	1.1151345	9.5 Layers
	1.244E-03	0.0120301	18.5 Layers	5.716E-04	1.3592095	8.5 Layers
	1.177E-03	0.0421553	17.5 Layers	5.044E-04	1.6260028	7.5 Layers
	1.110E-03	0.0951084	16.5 Layers	4.371E-04	1.9366935	6.5 Layers
	1.042E-03	0.1714608	15.5 Layers	3.699E-04	2.2691972	5.5 Layers
	9.751E-04	0.2705721	14.5 Layers	3.026E-04	2.6432536	4.5 Layers
	9.079E-04	0.3911336	13.5 Layers	2.354E-04	3.0861670	3.5 Layers
	8.406E-04	0.6377815	12.5 Layer	1.681E-04	3.6316863	2.5 Layers
	7.734E-04	0.7064605	11.5 Layers	1.009E-04	4.1413897	1.5 Layers
	7.061E-04	0.8970608	10.5 Layers	3.362E-05	4.8960244	0.5 Layers
			1.49	Average MeV for Escaping Alphas		
			4.599E+13	Source Particles/second		
			1.276E+11	Particles/sec POTENTIALLY Escaping		
			1.895E+11	MeV/second Escaping		
			1.895E+15	Molecules/second Formed		
			0.0992	Moles / Year per Asbl		
			0.0063	Kilograms /Year per Asbl		

Worksheet for Alpha Particle Transport Calculation One Thousand Years Cool Time						
Material: UO2	Density:	10.4	Radius:	0.4845		
B&W15x15, 5.05w/oU-235		(gram/cc)		(cm)		
55,000 MWd/MTU	Maximum					
Source (Ci/Asbl)	Energy (MeV)	Abundance Fraction	Source (a/second)	Power (MeV/s)	Fraction of Total P	
U-234	1.83E+00	4.77	1.00	6.771E+10	3.230E+11	0.0014
U-235	1.04E-02	4.58	0.83	3.194E+08	1.463E+09	0.0000
U-238	1.46E-01	4.20	1.00	5.402E+09	2.269E+10	0.0001
Np-237	8.71E-01	4.78	0.87	2.804E+10	1.340E+11	0.0006
Pu-238	1.64E+00	5.50	1.00	6.068E+10	3.337E+11	0.0015
Pu-239	2.02E+02	5.16	0.89	7.399E+12	3.618E+13	0.1709
Pu-240	2.89E+02	5.17	1.00	1.069E+13	5.628E+13	0.2474
Pu-241	3.76E-01	4.90	2.30E-05	3.200E+05	1.568E+06	0.0000
Pu-242	1.46E+00	4.90	1.00	5.402E+10	2.647E+11	0.0012
Am-241	7.07E+02	5.49	0.87	2.276E+13	1.248E+14	0.5592
Am-243	2.01E+01	5.30	1.00	7.437E+11	3.642E+12	0.0176
		Total:	4.181E+13	2.234E+14	1.0000	
	Mean Source Alpha Energy: (MeV)					5.34
	Maximum Range for Alphas:					1.341E-03
Pellet Radius:	0.4845					
Range (cm):	1.341E-03					
Non-escape R:	0.4832					
Escape Fraction:	0.0027640	(Half-Space, Portion of the Source which MIGHT Escape))				
Mean Energy:	5.34					
DeltaX: (cm)	6.705E-05					
Number of Steps:	20	(EBAR Values)				
PATH (cm)	1.307E-03	0.0010695	19.5 Layers	6.370E-04	1.1114895	9.5 Layers
	1.240E-03	0.0118112	18.5 Layers	5.699E-04	1.3549595	8.5 Layers
	1.173E-03	0.0418032	17.5 Layers	5.029E-04	1.6211859	7.5 Layers
	1.106E-03	0.0944751	16.5 Layers	4.358E-04	1.9311639	6.5 Layers
	1.039E-03	0.1704926	15.5 Layers	3.688E-04	2.2629165	5.5 Layers
	9.722E-04	0.2692261	14.5 Layers	3.017E-04	2.6363078	4.5 Layers
	9.052E-04	0.3893782	13.5 Layers	2.347E-04	3.0781947	3.5 Layers
	8.381E-04	0.6356183	12.5 Layer	1.676E-04	3.5228956	2.5 Layers
	7.711E-04	0.7038265	11.5 Layers	1.006E-04	4.1314426	1.5 Layers
	7.040E-04	0.8939435	10.5 Layers	3.352E-05	4.8845336	0.5 Layers
			1.48	Average MeV for Escaping Alphas		
			4.181E+13	Source Particles/second		
			1.156E+11	Particles/sec POTENTIALLY Escaping		
			1.713E+11	MeV/second Escaping		
			1.713E+15	Molecules/second Formed		
			0.0897	Moles / Year per Asbl		
			0.0056	Kilograms /Year per Asbl		

Alpha-211-2 Production/Material Loss Table Packaged B&W 15x15 @ 0.05Wt% 65,000 MWD/MTU		
Time (Years)	Moles/Year	kg/Year
5	0.4212	0.0265
100	0.4095	0.0258
150	0.3459	0.0218
200	0.2968	0.0187
250	0.2595	0.0163
300	0.2309	0.0145
400	0.1900	0.0120
500	0.1620	0.0102
600	0.1405	0.0089
700	0.1238	0.0078
800	0.1106	0.0070
900	0.0992	0.0063
1000	0.0897	0.0056
Per Asbl	Per Asbl	
Total (100-1000Y)	169.76	10.0648

Moles/900Y kg/900Y  
 Per 21 Asbl Per 21 Asbl  
 3354.92 211.36

**Attachment V: SAS2H Input for PWR Assembly**

=sas2h parm='halt16,skipcellwt,skipshipdata'

SAS2H: BW15x15, Fuel Region Source, 4.20wt%, 48GWd/MTU burn, DBF

27burnuplib latticecell

' mixtures of fuel-pin-unit-cell:

' den=mass UO2/Volume assembly (see section 7.2.1 of report)

uo2 1 den=10.2076 1 922 92235 4.20000 92234 0.02490 92236 0.01932  
92238 95.74407 end

kr-83 1 0 1-20 922 end

kr-85 1 0 1-20 922 end

sr-90 1 0 1-20 922 end

y-89 1 0 1-20 922 end

mo-95 1 0 1-20 922 end

zr-93 1 0 1-20 922 end

zr-94 1 0 1-20 922 end

zr-95 1 0 1-20 922 end

nb-94 1 0 1-20 922 end

tc-99 1 0 1-20 922 end

rh-103 1 0 1-20 922 end

rh-105 1 0 1-20 922 end

ru-101 1 0 1-20 922 end

ru-106 1 0 1-20 922 end

pd-105 1 0 1-20 922 end

pd-108 1 0 1-20 922 end

ag-109 1 0 1-20 922 end

sb-124 1 0 1-20 922 end

xe-131 1 0 1-20 922 end

xe-132 1 0 1-20 922 end

xe-135 1 0 1-20 922 end

xe-136 1 0 1-20 922 end

cs-134 1 0 1-20 922 end

cs-135 1 0 1-20 922 end

cs-137 1 0 1-20 922 end

ba-136 1 0 1-20 922 end

la-139 1 0 1-20 922 end

pr-141 1 0 1-20 922 end

pr-143 1 0 1-20 922 end

ce-144 1 0 1-20 922 end

nd-143 1 0 1-20 922 end

nd-145 1 0 1-20 922 end

pm-147 1 0 1-20 922 end

pm-148 1 0 1-20 922 end

nd-147 1 0 1-20 922 end

sm-147 1 0 1-20 922 end

sm-149 1 0 1-20 922 end  
sm-150 1 0 1-20 922 end  
sm-151 1 0 1-20 922 end  
sm-152 1 0 1-20 922 end  
gd-155 1 0 1-20 922 end  
eu-153 1 0 1-20 922 end  
eu-154 1 0 1-20 922 end  
eu-155 1 0 1-20 922 end  
arbm-zirc4 6.565 0 0 0 8016 0.12 24000 0.10 26000 0.20 50000 1.40  
40000 98.18 2 1.0 620.9 end  
h2o 3 den=0.71378 1.0 578.9 end  
arbm-bormod 0.71378 1 1 0 0 5000 100.0 3 552.6e-6 578.9 end  
  
' 1050 ppm boron max BOC; 552.6 ppm cycle ave.  
'-----  
end comp  
  
'-----  
  
' fuel-pin-cell geometry:  
  
squarepitch 1.44272 0.936244 1 3 1.0922 2 0.95758 0 end  
  
'-----  
  
' assembly unit cell parameters:  
npin/assm=208 .fuelngth=360.172 ncycles=1 nlib/cyc=16  
lightel=15 printlevel=5 inplevel=2 numholes=17  
numinstr=1 mxtube=2 ortube=0.6731 srtube=0.63246  
asmpitch=21.6814 numztotal=4 mxrepeats=1 mixmod=3  
facmesh=1.0 end  
  
3 0.63246 2 0.67310 3 0.814 500 2.961242  
  
'-----  
  
' cycle parameters:  
  
power=14.5085 burn=1537.8505 down=1 end  
  
'-----  
  
' light elements for activation:  
  
ni 2.6460 cr 1.0632 co 0.0490 mo 0.1495 nb 0.2450  
ti 0.0392 al 0.0294 c 0.0029 mn 0.0123 si 0.0123  
cu 0.0098 fe 1.0381 o 0.1587 sn 1.8510 zr 129.8046

end  
end  
=origens  
0\$\$ a8 26 a11 71 e  
1\$\$ 1  
1t  
B&W 15x15, 4.2%/48086 MWd/MTU Decay  
3\$\$ 21 0 1 a33 -88  
2t  
3\$\$\$ 0  
4t  
56\$\$ 0 10 a14 5 3 0 4 e  
5t  
Part B B&W 15x15, 4.20wt%, 48086 MWd/MTU Decay  
per B&W 15x15 assembly, 464 kg U Loading  
60\*\* 5 50 100 150 200 250 300 400 500 600  
65\$\$ 27z 1 1 1 e  
6t  
56\$\$ 0 4 a14 5 a17 4 e 57\*\* 600 e  
5t  
60\*\* 700 800 900 1000  
65\$\$ 27z 1 1 1 e  
6t  
56\$\$ f0 t  
end